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Generation of High Fidelity Covariance Data Sets for the Natural Molybdenum Isotopes Including a Series of Molybdenum Sensitive Critical Experiment Designs

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Generation of High Fidelity Covariance Data Sets for the Natural Molybdenum Isotopes Including a Series of Molybdenum Sensitive Critical Experiment Designs

by

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Dedication

To Amy.

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The University of Texas at Austin, 2013

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Quantification of uncertainty in computational models of nuclear systems is required for assessing margins of safety for both design and operation of those systems. The largest source of uncertainty in computational models of nuclear systems derives from the nuclear cross section data used for modeling. There are two parts to cross section uncertainty data: the relative uncertainty in the cross section at a particular energy, and how that uncertainty is correlated with the uncertainty at all other energies. This cross section uncertainty and uncertainty correlation is compiled as covariance data. High fidelity covariance data exists for a few key isotopes, however the covariance data available for many structural materials is considered low fidelity, and is derived primarily from integral measurements with little meaningful correlation between energy regions. Low fidelity covariance data is acceptable for materials to which the operating characteristics of the modeled nuclear system are insensitive. However, in some cases, nuclear systems can be sensitive to isotopes with only low fidelity covariance data. Such is the case for the new U(19.5%)-10Moly foil fuel form to be produced at the Y-12 National Security Complex for use in research and test reactors. This fuel is ten weight percent molybdenum, the isotopes of which have only low fidelity covariance data.

Improvements to the molybdenum isotope covariance data would benefit the modeling of systems using the new fuel form. This dissertation provides a framework for deriving high fidelity molybdenum isotope covariance data from a set of elemental molybdenum experimental cross section results. Additionally, a series of critical experiments featuring the new Y-12 fuel form was designed to address deficiencies in the critical experiment library with respect to molybdenum isotopes. Along with existing molybdenum sensitive critical experiments, these proposed experiments were used as a basis to compare the performance of the new high fidelity molybdenum covariance data set with the existing low fidelity covariance data set using the nuclear modeling code SCALE. The use of the high fidelity covariance data was found to result in reduced overall bias, reduced bias due to the molybdenum isotopes, and improved goodness-of-fit of computational results to experimental results.

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Chapter 1: Introduction

As advanced nuclear fuels are being developed, increasing attention is being paid to assessing uncertainty in the physics of nuclear systems and associated sensitivities in both system design and operation. Characteristics of nuclear systems such as multiplication factor, flux, and dose levels are often sensitive to variables such as system dimensions and operating environment, which may have some level of associated uncertainty. However, the greatest source of uncertainty in most real world nuclear systems arises from the evaluated nuclear data used for reactor physics modeling [1].

The use of accurate cross-section data is critical to modeling nuclear systems. Cross-section data is typically derived from a combination of experimental measurements and particle interaction models. Both of these sources inevitably contain some uncertainty. Uncertainty in experimental data arises from systematic error or bias as well as variables in the experimental systems that are difficult or impossible for the experimenter to control. Uncertainty in interaction models derives from the differences between the model's approximations and the physical reality of the particle interaction.

To be taken into account, this uncertainty data must be assessed and compiled in evaluated nuclear data files in a format that can be used in analysis code packages. A suitable format for this uncertainty data, referred to as covariance data and including both the relative uncertainty in the cross section at a given energy and the how that uncertainty is correlated with uncertainty at other energies, has been included in the last two generations of ENDF [2][3][4]. High fidelity covariance data has been produced for key isotopes such as ^{235}U, ^{238}U, ^{239}Pu, and ^{1-3}H [5]. However, the majority of fission product isotopes and isotopes found in structural reactor components either lack covariance data entirely or has low fidelity data only [6]. This can be problematic when isotopes lacking high fidelity covariance data comprise significant fractions of fuel material, such as is the case for the low enriched U-10Moly fuel form developed at the Y-12 National Security Complex.

In conjunction with the Reduced Enrichment for Research and Test Reactors (RERTR) program of the DOE, Y-12 has developed a monolithic uranium-molybdenum foil fuel form, which will first be used in the Advanced Test Reactor at Idaho National Laboratory [7][8]. This fuel form is advantageous for non-proliferation reasons as at 19.5% ^{235}U it is low-enriched while maintaining the uranium density of high enriched fuels which it will be replacing. The ten weight percent molybdenum provides structural stability to the fuel as well as helping to prevent swelling due to irradiation. But there is currently no high fidelity covariance data for the molybdenum isotopes, only low-fidelity covariance data derived from integral measurements. But if molybdenum makes up a substantial fraction of the fuel material itself, higher quality uncertainty data for molybdenum cross-section data is desired.

Once a new cross section or covariance evaluation has been completed, the next step is to validate the new data. One of the primary means of doing so is through the use of critical benchmark experiments. Critical benchmark experiments are used to determine critical parameters, such as mass and geometry specifications, for combinations of fuel, moderator, reflector, and other structural elements. At their most simple, a critical benchmark experiment might take the form of a bare sphere or cylinder of uranium metal. At the other end of the spectrum, complex arrays of moderated and reflected fuel elements could form a benchmark experiment. Critical benchmark experiments seek to provide a means of mimicking the operating characteristics of real world nuclear systems at the lab level. As such, they are performed at various nuclear critical facilities throughout the world. The results of critical benchmarks are most often used in criticality safety studies to validate computational methods of establishing minimum safe subcritical margins for operations with fissile materials. Additionally, critical benchmarks can also be used in validation of nuclear cross section data, as computational integral system parameters such as k_{eff} derive ultimately from the underlying nuclear cross section data. However, in order for critical benchmarks to serve their purpose with regards to real world nuclear systems, they must have a degree of similarity to the real world system in terms of shared cross section data and neutron spectra. There is currently a lack of critical experiments exhibiting this degree of similarity to the new U-Moly fuel form previously discussed, particularly in regards to molybdenum serving as an integral constituent of the fuel, and to the system having a thermalized spectrum as in the Advanced Test Reactor.

A key goal of this research project is to provide a new set of high fidelity covariance data for the naturally occurring molybdenum isotopes utilizing a newly completed experimental evaluation of molybdenum cross-section data by Rensselaer Polytechnic Institute and the retroactive approach of the SAMMY code package. The experimental data provided by RPI is for an elemental molybdenum sample, from which isotopic high fidelity covariance data will be generated. Deriving isotopic covariance data from an elemental sample has not previously been attempted, this work should illustrate a new potential capability of the SAMMY code package. The improved covariance data produced will make possible more accurate modeling of nuclear systems containing molybdenum; in particular sensitivity and uncertainty studies of such systems will benefit. The final goal of this portion of the project would see the new set of molybdenum covariance data distributed in an ENDF nuclear data release.

Additionally, a series of critical experiments will be designed, featuring a new U(19.5%)-10Mo fuel form, which will address deficiencies in the current critical experiment database with respect to the molybdenum isotopes. The design of this series of experiments will be based on prior critical experiments, and will seek to characterize the effects of molybdenum isotope cross section data throughout the energy region. The final goal of this portion of the project would see the new series of critical experiments submitted for eventual completion at the National Criticality Experiments Research Center.

The remainder of this document is organized as follows: chapter 2 provides a literature review and theoretical overview, chapter 3 details existing molybdenum sensitive critical experiments and a set of proposed benchmark critical experiments to utilize the U(19.5%)-10Mo fuel, chapter 4 details the method used to generate high fidelity covariance data for the molybdenum isotopes, chapter 5 compares uncertainty studies of the proposed critical experiment designs using the existing low fidelity molybdenum covariance data and the newly generated high fidelity covariance data, and finally chapter 6 presents conclusions to this work.

Chapter 2: Literature Review and Theory

NUCLEAR DATA

Interaction Cross Section Data

Nuclear interaction cross section data is fundamental to all nuclear engineering and design. This data describes the probability of interactions occurring between the nuclei of atoms and neutrons incident on those nuclei, in terms of the relative energy between the nuclei and neutrons.

Cross section data is typically derived from a combination of experimental measurements and interaction models.

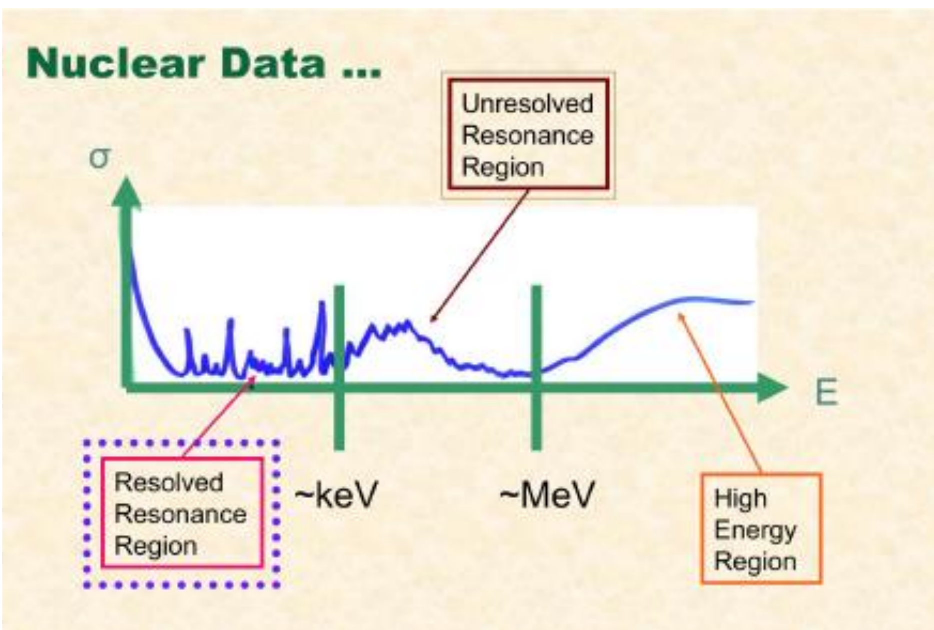

Figure 1) Generalized cross-section regions

Nuclear cross-section data is customarily organized into general regions based on the behavior of the cross-section in those regions, i.e. thermal, resolved resonance, unresolved resonance, and high energy regions, as shown above in figure 1.

Of particular interest to this work is the resolved resonance region. Within this energy domain the cross-section can vary dramatically with respect to incident neutron energy. These sudden spikes in the cross-section are due to the formation of a relatively stable compound nucleus of the target nucleus and incident neutron of a specific energy. A real world example of the ^{238}U total cross section is given below in figure 2.

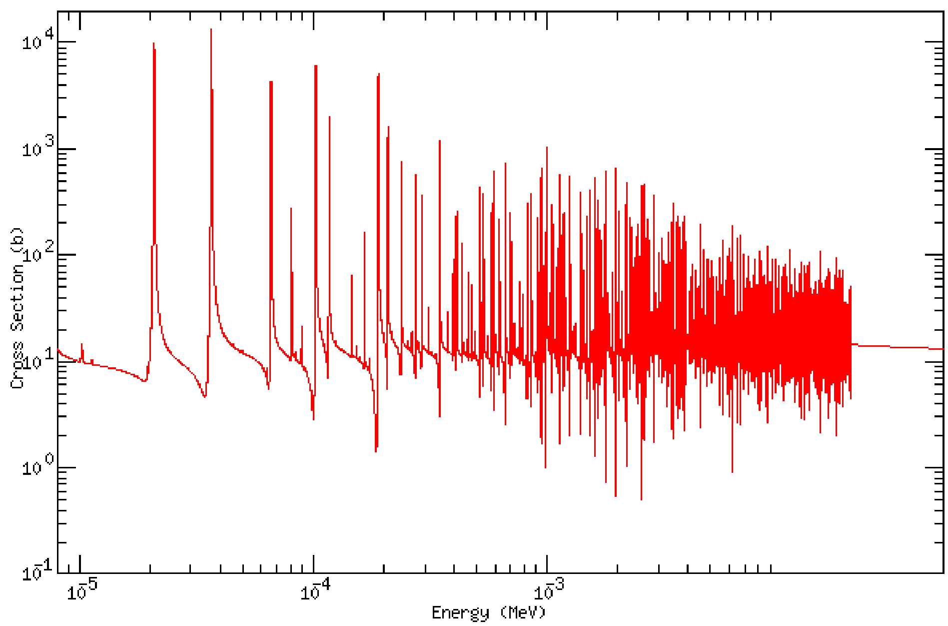

Figure 2) ^{238}U total cross section resolved resonance region

Such rapidly varying cross-sections would be difficult and unwieldy to describe adequately with point-wise data. R-matrix theory was developed to address the need for a compact and accurate means of describing the resolved resonance region [9].

While R-matrix theory is a complicated generalized interaction theory, a summary will be provided here. A simplified case neglecting spin dependence will be used, which will condense the mathematics considerably while containing the essential elements of the theory. R-matrix theory treats the interior potential of a nuclear interaction as a black box; therefore the wave function behavior of the compound nucleus cannot be calculated directly from Schrödinger's equation. The following derivation is taken from reference [10]. The inner wave function of the angular momentum is expanded in a linear combination of the eigenfunctions of the energy levels of the compound nucleus:

$$\phi_l(E,r) = \sum_\lambda A_{l\lambda}\, \phi_l(E_\lambda, r) \tag{1}$$

Where $\phi_l(E,r)$ is the inner wave function at any energy E, and $\phi_l(E_\lambda, r)$ is the eigenfunction at the energy eigenvalue E_λ. Both $\phi_l(E,r)$ and $\phi_l(E_\lambda, r)$ are solutions of the radial Schrödinger's equations in the inner nucleus region given by

$$\left\{\frac{d^2}{dr^2} + \frac{2m}{\hbar^2}\left[E - V(r) - \frac{l(l+1)\hbar^2}{2mr^2}\right]\right\}\phi_l(E,r) = 0 \tag{2}$$

And

$$\left\{\frac{d^2}{dr^2} + \frac{2m}{\hbar^2}\left[E_\lambda - V(r) - \frac{l(l+1)\hbar^2}{2mr^2}\right]\right\}\phi_l(E_\lambda,r) = 0 \tag{3}$$

The above expressions are required to be finite at $r = 0$, therefore both functions vanish at that point, providing one boundary condition. The second boundary condition is provided by the requirement that the logarithmic derivative of the eigenfunction at the surface of the nucleus, defined as $r=a$, must be constant:

$$\left[\frac{d\phi_l(E_\lambda,r)}{dr}\right]_{r=a} = a^{-1}B_l\phi_l(E_\lambda,a) \tag{4}$$

B_l is an arbitrary boundary constant. Additionally, as eigenfunctions of a real Hamiltonian, the functions $\phi_l(E_\lambda,r)$ are orthogonal. Assuming they are also normalized gives

$$\int_0^a \phi_l(E_\lambda,r)\,\phi_l(E_{\lambda'},r)dr = \delta_{\lambda\lambda'} \tag{5}$$

Using equation 1 and the above orthogonality condition a solution for the coefficients $A_{l\lambda}$ can be found

$$A_{l\lambda} = \int_0^a \phi_l(E_\lambda,r)\,\phi_l(E_{\lambda'},r)dr \tag{6}$$

Solving the above requires multiplying equations 2 and 3 by $\phi_l(E_\lambda,r)$ and $\phi(E_\lambda,r)$ respectively, subtracting, and then integrating from *0* to *a*, resulting in

$$A_{l\lambda} = \frac{\hbar^2}{2m}(E_\lambda - E)^{-1}\left[\phi_l(E_\lambda,r)\frac{d\phi_l(E,r)}{dr} - \phi_l(E,r)\frac{d\phi_l(E_\lambda,r)}{dr}\right]_{r=a} \tag{7}$$

Inserting the above coefficient values into equation 1 at the nuclear surface, and using the derivative boundary condition results in the following form for the wave function:

$$\phi_l(E,a) = \frac{\hbar^2}{2ma}\sum_\lambda\left[\frac{\phi_l(E_\lambda,a)\phi_l(E_\lambda,a)}{E_\lambda - E}\right]\left[r\frac{d\phi_l(E,a)}{dr} - B_l\phi_l(E,r)\right]_{r=a} \tag{8}$$

Through equation 8 the value of the wave function in the inner region is related to the value of its derivative at the surface. The R-matrix can then be defined as:

$$R_l = \frac{\hbar^2}{2ma} \sum_\lambda \left[\frac{\phi_l(E_\lambda, a)\phi_l(E_\lambda, a)}{E_\lambda - E} \right] \tag{9}$$

Or more compactly as:

$$R_l = \sum_\lambda \frac{\gamma_{\lambda l}\gamma_{\lambda l}}{E_\lambda - E} \tag{10}$$

Where $\gamma_{\lambda l}$ is the reduced width amplitude for the level λ and angular momentum *l*, and is defined by

$$\gamma_{\lambda l} = \sqrt{\frac{\hbar^2}{2ma}} \phi_l(E_\lambda, a) \tag{11}$$

Therefore the reduced width amplitude depends on the wave function value at the nuclear surface, but not within the nucleus interior. E_λ and $\gamma_{\lambda l}$, the resonance energy and width respectively, are the unknown parameters of the R-matrix, values for which can be found by fitting to experimental cross-section data. The SAMMY R-matrix code can be used to fit experimentally measured cross-section data to E_λ and $\gamma_{\lambda l}$ values utilizing a generalized least-squares approach.

Equation 10 above relies on several simplifications, including neglecting the neutron-nucleus spin dependence and the several possible reaction processes which can occur. Generalizing equation 10 requires inclusion of these factors through the concept of "channels," each possible pair of nucleus and particle and the spin of such a pair is designated by its own channel. The initial particle-nucleus pair is referred to as the entrance channel (*c*), while the state of the final particle-nucleus pair is the exit channel (*c'*).

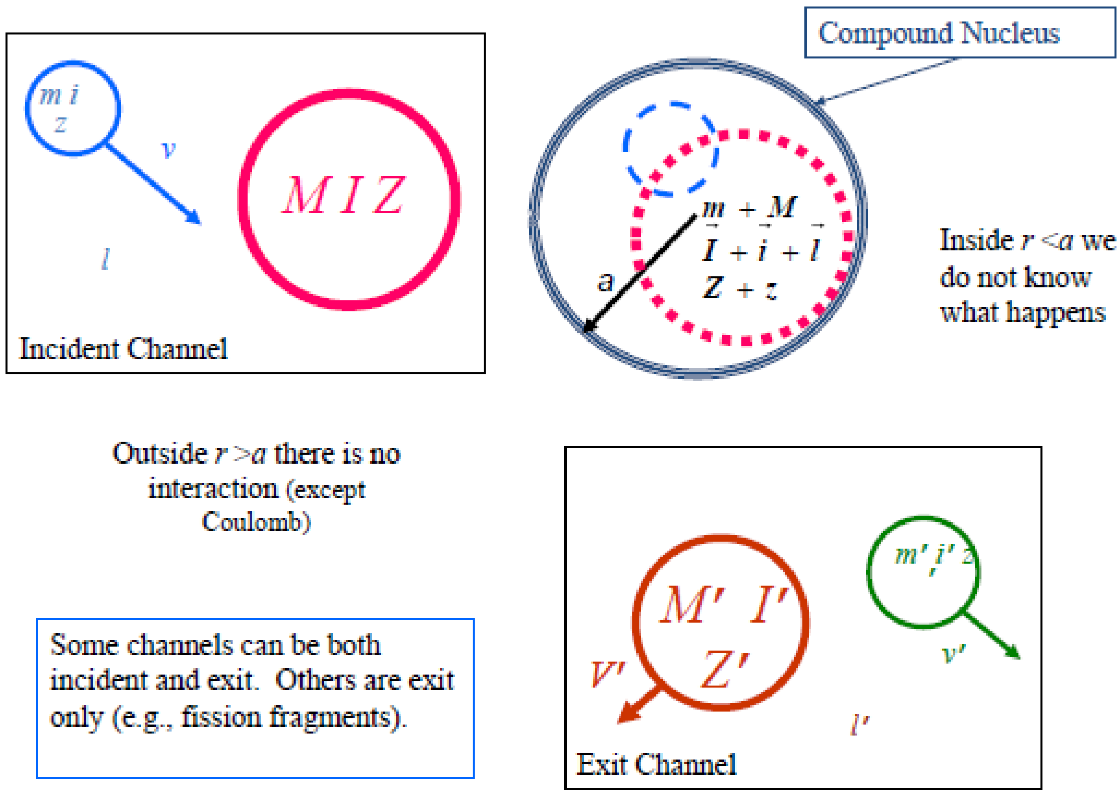

Figure 3) Channel interaction visualization [11]

The generalized R-matrix is given by:

$$R_{cc'} = \sum_{\lambda} \frac{\gamma_{\lambda c}\gamma_{\lambda c'}}{E_{\lambda} - E} \tag{12}$$

The generalized reduced width amplitude is given by:

$$\gamma_{\lambda c} = \sqrt{\frac{\hbar^2}{2m_c a_c}\phi_l(E_\lambda, a_c)} \tag{13}$$

It is not possible to express interaction cross-sections using solely the R-matrix. Doing so requires a means of relating the R-matrix to the chosen cross-section formalism through the collision matrix, also known as the U-matrix. The derivation of this relationship of R-matrix to U-matrix to cross-section formalism is not required for this work; however its final matrix form will be given here:

$$U = \rho^{1/2}\phi_{out}^{-1}[I - R(L - B)]^{-1}[I - R(\bar{L} - B)]\phi_{inc}\rho^{-1/2} \tag{14}$$

where U is the collision matrix, the matrix elements of $\rho^{1/2}$ are given by $(k_c a_c)^{1/2}$ for the interaction channel and k_c is the wave number of the incident neutron, ϕ_{inc} and ϕ_{out} are the incoming and outgoing wave form for the incident and resultant free particles of the interaction channels, I is the identity matrix, R is the R-matrix as previously defined, and L and $\bar{L}$ are the logarithmic derivative vectors whose elements are given by

$$L = \left(\frac{r}{\phi_l^{inc}}\frac{d\phi_l^{inc}}{dr}\right)_{r=a} \tag{15}$$

and

$$\bar{L} = \left(\frac{r}{\phi_l^{out}}\frac{d\phi_l^{out}}{dr}\right)_{r=a} \tag{16}$$

respectively. Interaction cross-sections are calculated as functions of the U-matrix. Therefore the generalized path from experimental data to cross-section data is:

- Experimental data (with uncertainties) is collected.
- An initial set of resonance parameters (E_λ and $\gamma_{\lambda c}$) are constructed, typically through inspection of the experimental data, or from a prior evaluation of experimental data for the isotope of interest.
- Using the initial set of resonance parameters, and a code such as SAMMY, a theoretical cross-section is generated using the chosen R-matrix formalism.

- Through iterative SAMMY runs the theoretical cross-section generated from the set of resonance parameters is fitted to the experimental data. Eventually a final best fit set of resonance parameters is found.
- These final resonance parameters, through the R-matrix and then the U-matrix can be used to generate interaction cross-sections through codes such as NJOY or AMPX.

The pertinent information above is E_λ and $\gamma_{\lambda c}$, the resonance energy and width, and their associated uncertainties. The workflow described below leads to derivation of covariance data for the resolved resonance region from those uncertainties.

Cross Section Covariance Data

As stated above, ENDF/B cross section data in the resolved resonance region is stored as R-matrix parameters. Cross-section processing codes such as NJOY or AMPX can interpret the stored parameters into usable working libraries of interaction cross-sections. In order to produce those parameters, processing codes such as SAMMY are used to fit experimental data to a chosen R-matrix formalism. Such an evaluation must also take into account sources of uncertainty in the experimental data.

There are many potential sources of experimental uncertainty, both statistical uncertainty associated with the measured values, as well as systematic uncertainty associated with the experimental set up. Sources of systematic uncertainty include normalization and background measurements, neutron time-of-flight and flight path measurements, measurements of sample thicknesses and composition, etc. These uncertainties must be taken into account through the evaluation process to produce the resonance-parameter covariance matrix. This matrix records the uncertainty for each resonance parameter (energy, widths), as well as correlation between the parameters.

Modern cross-section measurements are typically made using the time-of-flight method. A simplified diagram of a time-of-flight system is shown below in figure 4.

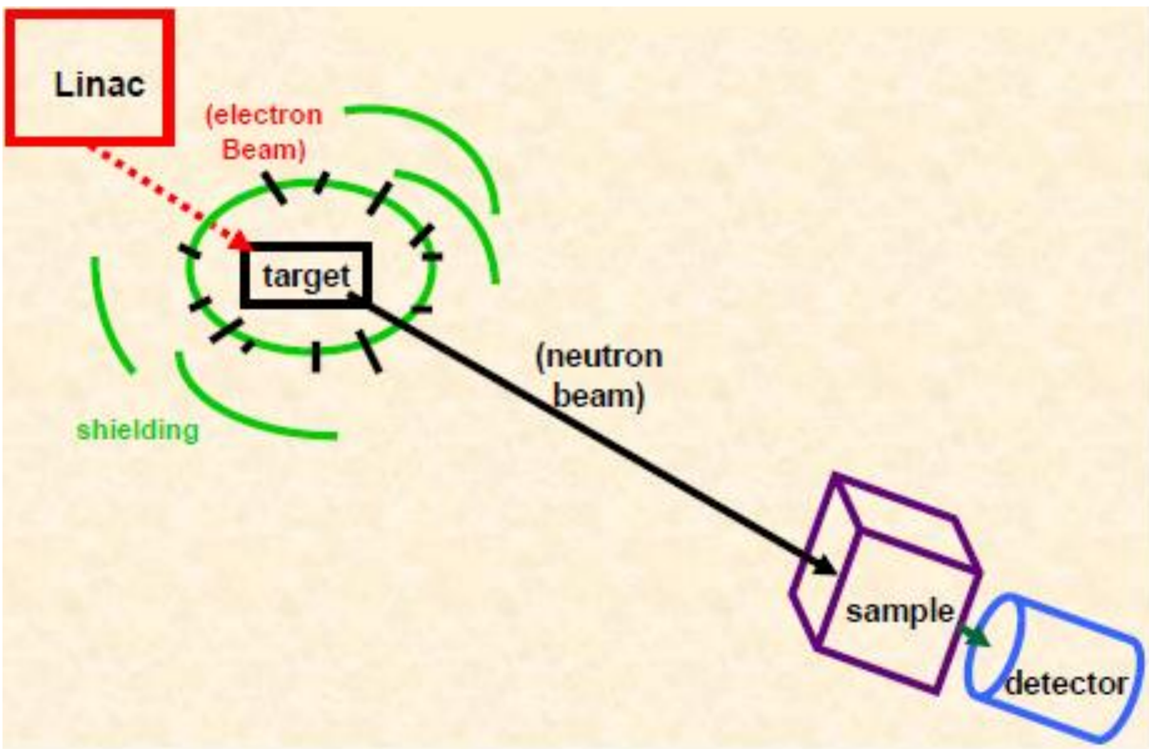

Figure 4) Example Time-of-Flight System

Accelerated electrons strike a high-Z target resulting in a flux of emitted neutrons. These neutrons can be collimated and moderated depending on experimental needs. The beam of emitted neutrons interacts with the sample to be studied. Detectors situated around the sample record the particles that reach them as a function of the time required for the particles to travel from the target to the detector, producing the "raw" experimental count data. This data is therefore counts vs. time of flight, which is further divided into bins or channels resulting in counts per time channel.

This raw data must next be converted to reduced data by correcting for detector dead time, subtracting background measurements, and normalizing with respect to the experiment duration. The following derivation is taken from reference [12]. The neutron time of flight can then be converted to neutron incident energy by:

:

$$E_i = mL^2/2t_i^2 \tag{17}$$

Where *m* is the neutron mass and *L* is the length of the flight path.

The collected raw data will obey Poisson statistics, meaning the uncertainty on the count measurement for a given channel will be the square root of that measurement. Generally, the counts per channel will be a very large number. In this case, it is acceptable to treat the Poisson distribution of the raw data as a normal distribution. Therefore the raw data count in each channel will be treated as independent and uncorrelated with all other channels.

The assumption of no correlation does not hold for reduced data. This can be demonstrated through the relatively simple processes of normalization and background subtraction. Normalization constants and background, *a* and *b* respectively, are measured by their own experiments, and each have associated uncertainty, Δa and Δb, which will be assumed constant with respect to energy for the sake of this example. The uncertainty on normalization and background derive from their own independent measurements, which also obey Poisson statistics. Therefore, Δa and Δb are the standard deviation of those measurements. These uncertainties are propagated to the reduced data, *d*. Therefore, the reduced data at energy E_1, d_1, is related to the reduced data d_2 at energy E_2

through the uncertainty propagation. This relationship can be described using the experimental data covariance matrix, V.

If r_i is the raw data point at time t_i, and d_i is the corresponding reduced data point at energy E_i as defined previously, then E_i is related to t_i by equation 14, and d_i is related to r_i by

$$d_i = (r_i - b)/a \qquad (18)$$

Uncertainties are known for each value on the right hand side of equation 18, therefore the covariance matrix for the experimental data can be determined as follows. First small increments are taken of each side of the equation:

$$\delta d_i = \frac{(\delta r_i - \delta b)}{a} - \frac{(r_i - b)\delta a}{a^2} = [\delta r_i - \delta b - d_i \delta a]/a \qquad (19)$$

Multiply each side by another small increment, $\boldsymbol{\delta d_j}$, and take expectation values.

$$\langle \delta d_i \delta d_j \rangle = \frac{\langle [\delta r_i - \delta b - d_i \delta a][\delta r_j - \delta b - d_j \delta a] \rangle}{a^2} = \left\{ \langle \delta r_i \delta r_j \rangle + \langle \delta^2 b \rangle + d_i d_j \langle \delta^2 a \rangle \right\}/a^2 \qquad (20)$$

All off diagonal terms have been eliminated from equation 20, based on the assumption that the different quantities were measured separately and are therefore uncorrelated. The experimental data covariance matrix can therefore be written

$$\boldsymbol{V_{ij} = \langle \delta d_i \delta d_j \rangle = \left\{ \Delta^2 r_i \delta_{ij} + \Delta^2 b + d_i d_j \Delta^2 a \right\}/a^2} \qquad \textbf{(21)}$$

Now with properly reduced experimental data and its covariance matrix, it is possible to move forward with the evaluation process with the final goal of producing evaluated nuclear data.

This evaluated data combines the best reduced cross-section measurements with the best theoretical knowledge of the cross-section shape, via R-matrix theory formalism, along with adjustments of the “true” cross-section due to real-world effects such as resolution or Doppler broadening, or finite sample size effects. Accomplishing this type of evaluation requires codes such as SAMMY, to determine the set of resonance parameters the best fit the reduced experimental data and the real world considerations. SAMMY will also produce the associated covariance matrix for the resonance parameter set, including both the statistical uncertainties introduced through the data reduction process, as well as systematic uncertainties introduced through the real world corrections. [13][14]

As stated previously, SAMMY utilizes a generalized least-squares method to fit its parameter set and covariance matrix. This Bayesian method for fitting the resonance parameters results in an updated resonance parameter set P as

$$P = P_0 + M' Y, \tag{22}$$

where M' is the associated resonance parameter covariance matrix, and is found by

$$M' = (M_0^{-1} + W)^{-1} \tag{23}$$

with W defined as

$$W = G^t V^{-1} G\,, \tag{24}$$

and Y is defined as an auxiliary matrix given by,

$$Y = G^t V^{-1}(D-T) \tag{25}$$

Above, P_0 is the initial parameter set with associated resonance parameter covariance matrix M, which is unknown initially and therefore assumed to be diagonal and infinite, meaning $M^{-1}=0$. [15] V is the data covariance matrix as defined previously, T is the theoretical value corresponding to the experimental data D, and G is the sensitivity matrix of the theoretical values with respect to the parameters given by

$$G = \frac{\partial T}{\partial P} \tag{26}$$

SAMMY can and should utilize all available experimental data of all types in this fitting procedure, as well as the full covariance matrix for each data set. Integral constraints such as resonance integrals and thermal cross sections can also be included. Upon completion, the final parameter set P can be written in ENDF File 2 format for inclusion in evaluated nuclear data files, while the covariance matrix M can be stored in ENDF File 32 format.

CURRENT MOLYBDENUM CROSS SECTION AND COVARIANCE DATA

As an initial investigation into molybdenum cross-section uncertainty, existing cross-section data from differing libraries was compared. Three existing data libraries were chosen: ENDF, maintained by Brookhaven National Laboratory in the US, JEFF maintained by the OECD Nuclear Energy Agency, and JENDL, maintained by the Japan Atomic Energy Agency. The most recent versions of these libraries (ENDF/B-VII.1, JEFF-3.1.1, JENDL-4.0) were obtained from the National Nuclear Data Center for the naturally occurring molybdenum isotopes:

^{92}Mo (14.84%) ^{94}Mo (9.25%) ^{95}Mo (15.92%) ^{96}Mo (16.68%)

^{97}Mo (9.55%) ^{98}Mo (24.13%) ^{100}Mo (9.63% , 1.2E19 Y)

The processing code NJOY was used to produce 238-group libraries for the molybdenum isotopes, shown below for ^{97}Mo total cross-section as an example in figure 5 [16].

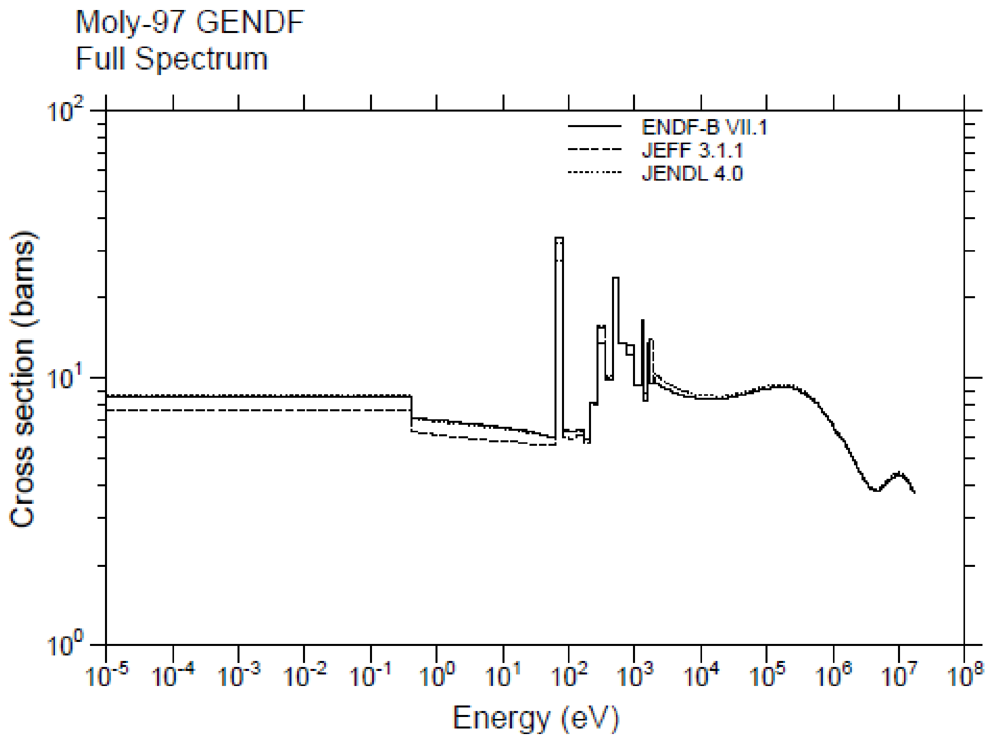

Figure 5) ^{97}Mo 238-group library comparison (total cross section)

Significant differences between libraries are evident, particularly in the resolved resonance and high energy regions.

The energy region limits imposed by the different libraries was determined for the isotopes, shown below in tables 1 through 7.

Table 1) ^{92}Mo Energy Region Limits

^{92}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10^{-5} eV – 40 KeV	10^{-5} eV – 50 KeV	10^{-5} eV – 50 KeV
Unresolved Resonance	40 KeV – 100 KeV	50 KeV - 100 KeV	50 KeV – 1 MeV
High Energy	100 KeV – 20 MeV	100 KeV – 20 MeV	1 MeV – 20 MeV

Table 2) ^{94}Mo Energy Region Limits

^{94}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 20 KeV	10e-5 eV – 20 KeV	10e-5 eV – 20 KeV
Unresolved Resonance	20 KeV – 100 KeV	20 KeV – 100 KeV	20 KeV – 1 MeV
High Energy	100 KeV – 20 MeV	100 KeV – 20 MeV	1 MeV – 20 MeV

Table 3) ^{95}Mo Energy Region Limits

^{95}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 2.1412 KeV	10e-5 eV – 2.1412 KeV	10e-5 eV – 2 KeV
Unresolved Resonance	2.1412 KeV – 206.2685 KeV	2.1412 KeV – 206.2685 KeV	2 KeV – 400 KeV
High Energy	206.2685 KeV – 20 MeV	206.2685 KeV – 20 MeV	400 KeV – 20 MeV

Table 4) ^{96}Mo Energy Region Limits

^{96}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 19 KeV	10e-5 eV – 19 KeV	10e-5 eV – 19 KeV
Unresolved Resonance	19 KeV – 100 KeV	19 KeV – 100 KeV	19 KeV – 1 MeV
High Energy	100 KeV – 20 MeV	100 KeV – 20 MeV	1 MeV – 20 MeV

Table 5) ^{97}Mo Energy Region Limits

^{97}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 2 KeV	10e-5 eV – 1.8 KeV	10e-5 eV – 1.8 KeV
Unresolved Resonance	2 KeV – 100 KeV	1.8 KeV – 100 KeV	1.8 KeV – 300 KeV
High Energy	100 KeV – 20 Mev	100 KeV – 2 MeV	300 KeV – 2 MeV

Table 6) ^{98}Mo Energy Region Limits

^{98}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 32 KeV	10e-5 eV – 32 KeV	10e-5 eV – 32 Kev
Unresolved Resonance	32 KeV – 100 KeV	32 KeV – 100 KeV	32 KeV – 1 MeV
High Energy	100 KeV – 20 MeV	100 KeV – 20 MeV	1 MeV – 20 MeV

Table 7) ^{100}Mo Energy Region Limits

^{100}Mo	ENDF/B-VII.1	JEFF-3.1.1	JENDL-4.0
Resolved Resonance	10e-5 eV – 26 KeV	10e-5 eV – 26 KeV	10e-5 eV -26 KeV
Unresolved Resonance	26 KeV – 100 KeV	26 KeV – 100 KeV	26 KeV – 1 MeV
High Energy	100 KeV – 20 MeV	100 KeV – 20 MeV	1 MeV – 20 MeV

In general, the ENDF and JEFF libraries used similar energy region structure. The JENDL library however consistently featured a broader unresolved resonance region than either the ENDF or JEFF libraries, appearing to not account for cross-section features that the ENDF and JEFF libraries used to define their energy regions.

The next comparison utilized the PREPRO cross-section processing code to compare the resolved resonance region structure of the three libraries [17]. Resolved resonance cross-sections are typically generated through interaction models defined by resonance parameters. These parameters are fit empirically to experimental data; however nuclear data libraries do not necessarily use the same resonance models or parameters.

Using the PREPRO summary output, the first noticeable difference between the JEFF and ENDF data is the number of resonances: for example, for ^{94}Mo, the ENDF data identifies 55 resonances while the JEFF data has 58. The JENDL data includes 59 resonances. In fact, for 3 out of 7 isotopes, there was not agreement between data libraries on how many resonances were present, as seen in table 8.

Table 8) Comparison of number of resonances for ENDF, JEFF, and JENDL libraries

	ENDF	JEFF	JENDL
^{92}Mo*	60	77	78
^{94}Mo*	55	58	59
^{95}Mo*	57	56	56
^{96}Mo	75	75	75
^{97}Mo*	66	66	66
^{98}Mo	158	158	158
^{100}Mo	124	124	124

Further differences between libraries are found upon closer inspection. Returning to ^{95}Mo, we can compare the number of resonances in each library for each combination of L and J quantum numbers, shown in table 9:

Table 9) ^{95}Mo resonances sorted by quantum numbers for ENDF, JEFF, and JENDL

	ENDF	JEFF	JENDL
L=0, J=2	9	10	10
L=0, J=3	14	11	11
L=1, J=1	2	4	5
L=1, J=2	12	7	10
L=1, J=3	14	13	10
L=1, J=4	6	11	10

Returning to table 8, all isotope libraries with asterisks had additional differences when sorted by quantum numbers. The number of resonances per set of quantum numbers differed more dramatically for even-odd isotopes. Furthermore, even when libraries shared the same resonances, the partial widths of the resonances could differ by as much as 30-40% in some cases.

In short, it would be difficult to trace back differences in group cross-sections or system parameters such as multiplication factor to individual resonance parameters as there are significantly more differences between the ENDF, JEFF and JENDL libraries than previously thought.

Clearly there is some uncertainty regarding the true values of molybdenum isotope cross sections. Such uncertainty is typically tabulated in covariance data files, the production of which is a key goal of this research work.

Currently, only the ENDF/B-VII.1 cross-section library includes covariance data for the molybdenum isotopes. However, this covariance data is low fidelity. It was generated as part of the Low Fidelity Covariance Project, a joint undertaking between Oak Ridge National Laboratory, Brookhaven National Laboratory, and Los Alamos National Laboratory. The goal of that project was to quickly and transparently produce modeling usable uncertainty estimates for all isotopes in ENDF. In order to accomplish this, the process for producing covariance data had to be extremely streamlined. For structural materials and fission products, integral uncertainty measurements (2200 m/s cross section, thermal capture, resonance integral) were assigned as the uncertainty values for whole energy regions (thermal, resonance) and were coupled with high energy covariance data generated at BNL. Complete correlation was assigned throughout the energy domain.

As an example, figures 6 and 7 below show the current low fidelity elastic scattering and capture covariance data for ^{97}Mo as is available in ENDF/B-VII.1. As a comparison, figures 8 and 9 show high fidelity elastic scattering and capture covariance data for ^{235}U.

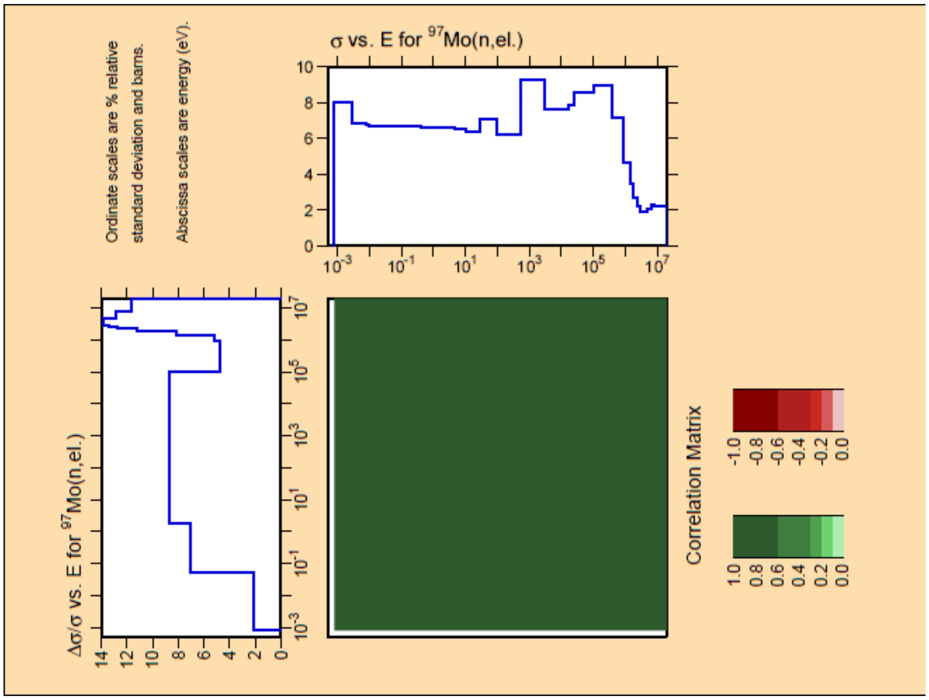

Figure 6) ^{97}Mo Low Fidelity Elastic Scattering Covariance Data

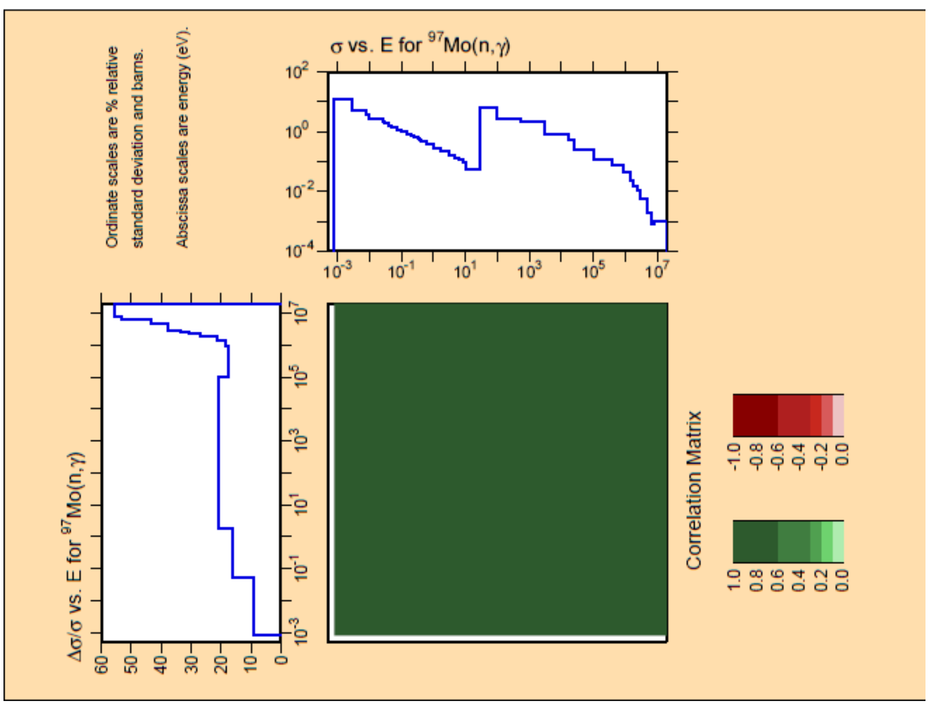

Figure 7) ^{97}Mo Low Fidelity Capture Covariance Data

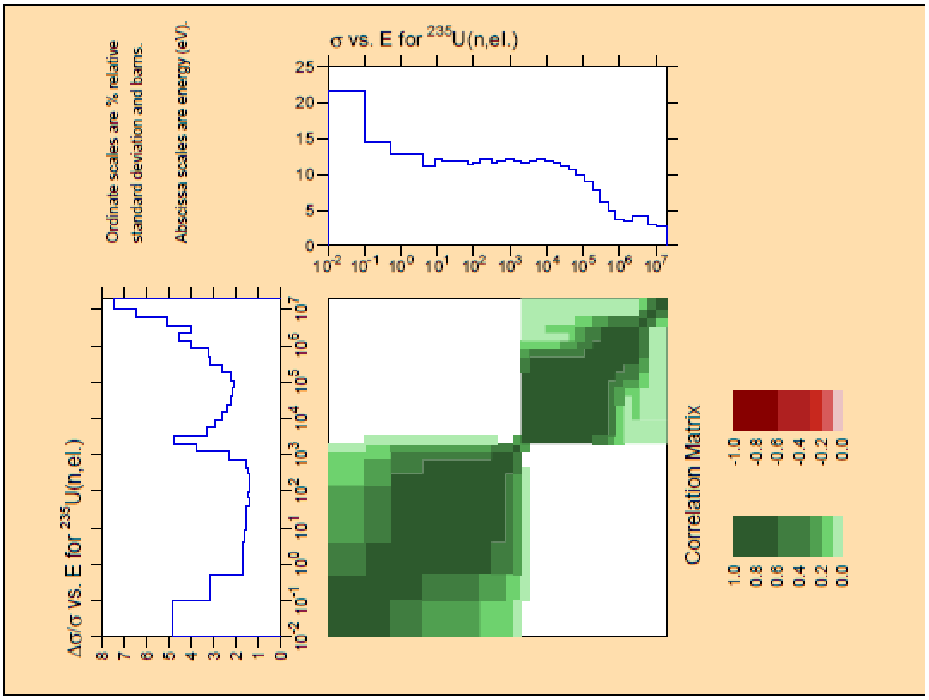

Figure 8) ^{235}U High Fidelity Elastic Scattering Covariance Data

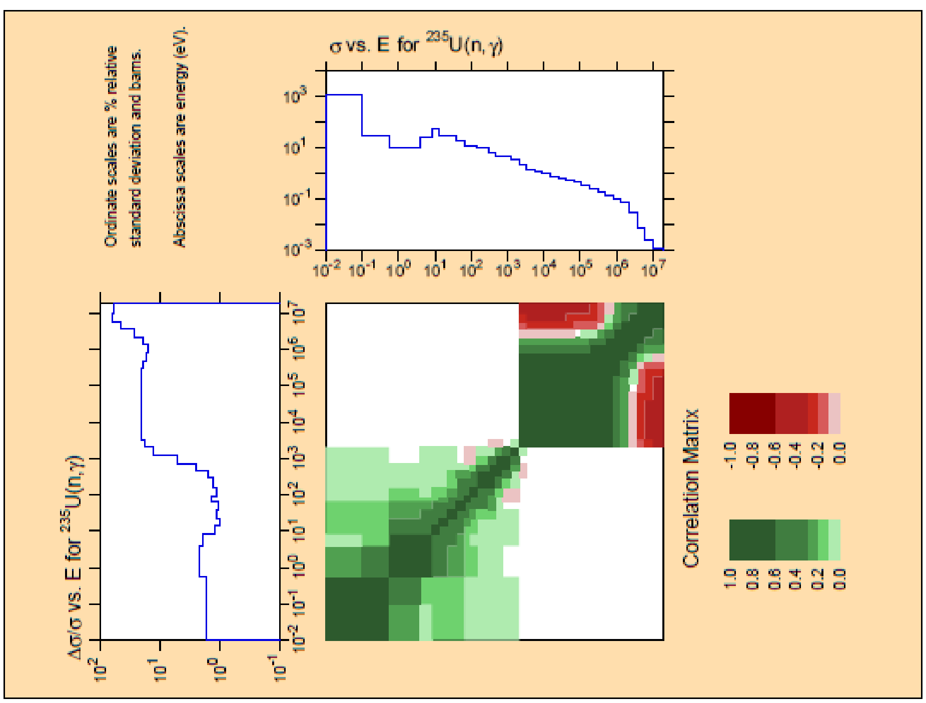

Figure 9) ^{235}U High Fidelity Capture Covariance Data

There are clear differences between the low and high fidelity covariance data. The molybdenum uncertainty data follows a very coarse stair-step as compared to the uranium uncertainty data. Additionally the correlation matrix for the uranium shows significant structure, whereas the low fidelity molybdenum data assigns blanket full correlation throughout all energy regions. However, the high uncertainty of the ^{235}U capture cross section should be noted.

Improvement to molybdenum covariance data should include increased resolution of correlations, as well as improved estimates of uncertainty.

EXISTING MOLYBDENUM SENSITIVE CRITICAL EXPERIMENTS

There are few critical experiments in existence which exhibit sensitivity to the molybdenum isotopes. In particular, very few critical experiments feature molybdenum as an integral component of the fuel material. Uranium-molybdenum alloy fuels were researched during the 1950s and 1960s, with little interest in the technology until recently.

Most of the criticality benchmark experiments catalogued by the International Criticality Safety Benchmark Evaluation Project which include molybdenum isotopes feature them as structural material, as molybdenum is used in some alloys of stainless steel, or as reflectors.

However, there are technical reports from a series of critical experiments completed in the early 1960s with the ORNL Fast Burst Reactor, later renamed the Health Physics Research Reactor, as well as critical experiments dating to the design phase for that reactor [18] [19].

The FBR was a Godiva type assembly, differing from the original Godiva reactors in that the constituent fuel was U(93.2%)-10Mo metal. A diagram of the reactor core is shown below in figure 10. Key reactor dimensions are given in the technical reports.

The critical experiments associated with the design of the FBR are likely to be more relevant for the purposes of this research. In these experiments a series of five critical assemblies of differing cylindrical and annular geometries were studied. One such assembly is shown below in figure 11. The technical reports for these experiments include material compositions and experimentally verified critical dimensions, generally cylinder or annulus heights, as well as critical masses.

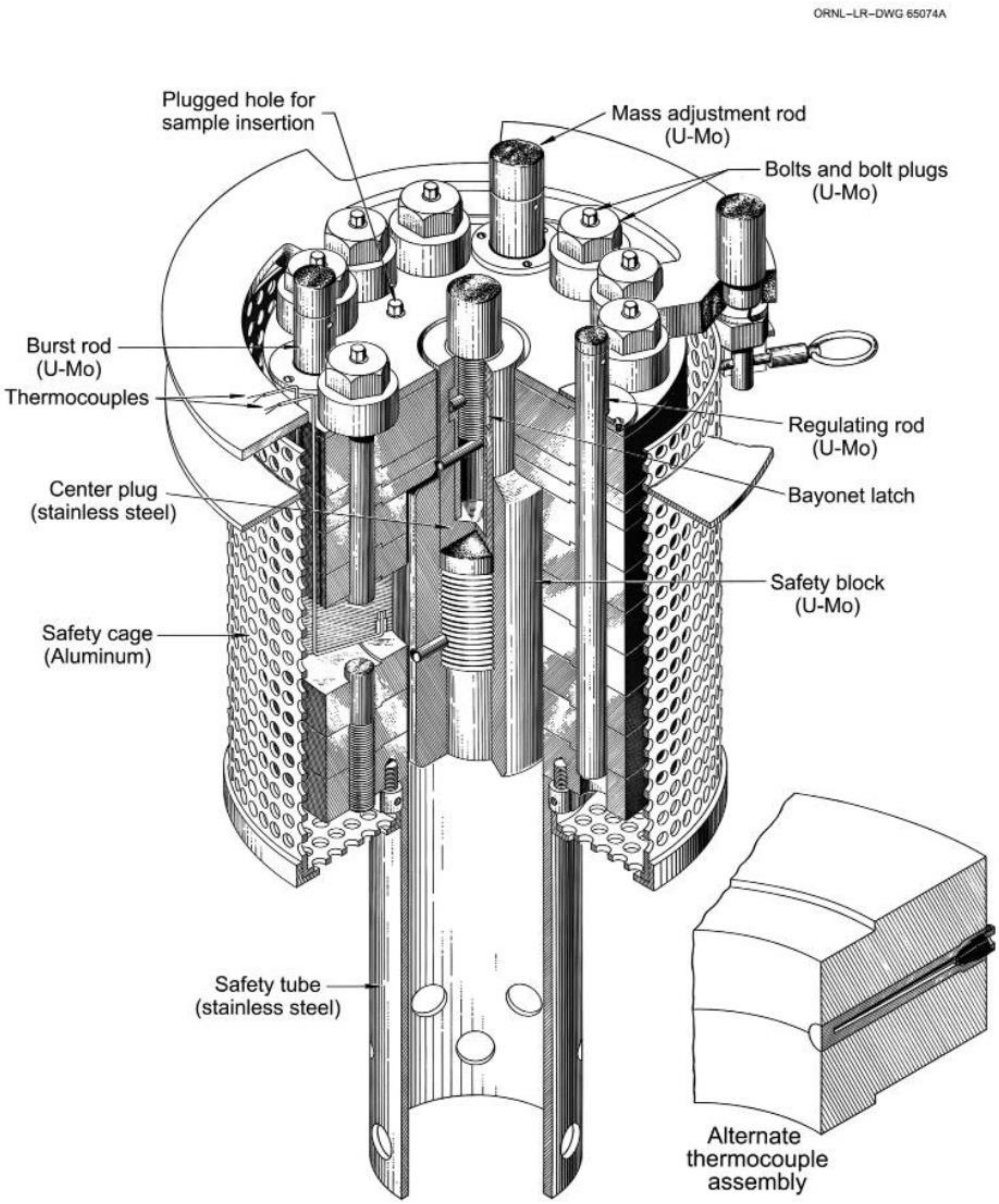

Figure 10) ORNL FBR Core Diagram

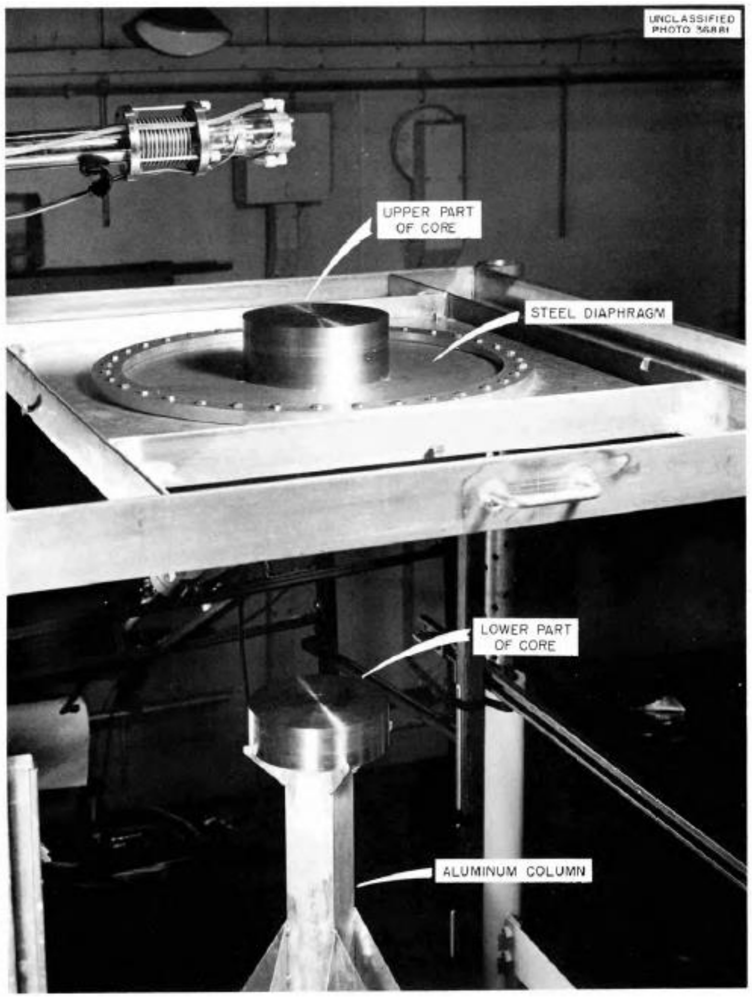

Figure 11) U-Mo cylindrical critical assembly experiment

The fuel for the FBR critical experiments was 93% enriched uranium metal, alloyed with 10 w/o natural molybdenum. While this fuel is of significantly higher enrichment than the U(19.5%)-10Mo fuel foils to be produced by Y-12, these critical experiments offer the only set of experimental data for systems in which molybdenum makes up a key component of the fuel itself.

The five FBR design critical experiments modeled are as follows:

ORNL FBR Crit. Exp. #1: Bare U-Mo metal cylinder, 20.32 cm diameter, 14.78 cm in height, 68.6 kg of ^{235}U.

ORNL FBR Crit. Exp. #2: Bare U-Mo metal annulus, 20.32 cm outer diameter, 5.08 cm diameter axial hole, 19.74 cm in height, 85.9 kg of ^{235}U.

ORNL FBR Crit. Exp. #3: U-Mo metal annulus, 20.32 cm outer diameter, 5.08 cm diameter steel core, 82.4 kg of ^{235}U.

ORNL FBR Crit. Exp. #4: U-Mo metal annulus, 20.32 cm outer diameter, 5.08 cm inner diameter, 5.08 cm thick Plexiglas on all sides, void in center, 12.57 cm in height, 47.2 kg of ^{235}U.

ORNL FBR Crit. Exp. #5: U-Mo metal annulus, 20.32 cm outer diameter, lower 12.7 cm of assembly has 8.89 cm inner diameter, remainder has 5.08 cm inner diameter, 2.54 cm thick Plexiglas on all sides, void in center, 13.86 cm in height, 52.8 kg of ^{235}U.

As mentioned previously, the ICSBEP does include some critical experiments which feature molybdenum as structural materials or reflectors. These experiments are described in table 10.

Table 10) ICSBEP Molybdenum Sensitive Critical Experiments [20]

ICSBEP Identifier	***Title***	***Role of Molybdenum***
HEU-MET-FAST-005-001 through 006	"Beryllium and Molybdenum Reflected Cylinders of Highly Enriched Uranium"	Reflector
HEU-SOL-THERM-001-001 through 002	"Minimally Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate"	Stainless steel tank
LEU-COMP-THERM-042-001 through 007	"Water-Moderated Rectangular Clusters of U(2.35)O_2 Fuel Rods (1.684 Cm Pitch) Separated by Steel, Boral, Boroflex, Cadmium, or Copper Plates, with Steel Reflecting Walls"	Steel reflecting walls and steel absorber plates
MIX-COMP-FAST-001-001	"ZPR-6 Assembly 7: A Cylindrical Assembly with Mixed (Pu,U)-Oxide Fuel and Sodium with a Thick Depleted-Uranium Reflector"	Pu-U-Mo fuel plates
U233-SOL-THERM-003-002 through 010	"Paraffin-Reflected 5-, 5.4-, 6-, 6.6-, 7.5-, 8-, 8.5-, 9-, and 12-Inch Diameter Cylinders of ^{233}U Uranyl Fluoride Solutions"	Impurities in solution
U233-SOL-THERM-009-001 through 004	"Unreflected Large-Diameter Cylinders of ^{233}U Uranyl Nitrate Solutions"	Stainless steel tank

The above critical experiments, along with the ORNL FBR critical experiments, comprise the set of critical experiment sensitivity responses which will be utilized in the sensitivity and uncertainty analysis for this work using the SCALE modules TSUNAMI and TSURFER. Additionally, they will reveal the deficiencies in existing molybdenum sensitive critical experiments, so as to inform the design process of new critical experiments to address those deficiencies.

SENSITIVITY AND UNCERTAINTY ANALYSIS

As interest in sensitivity and uncertainty analysis has increased over the past decade, S/U modules and capabilities have been incorporated into industry standard general analysis codes. One such code package is SCALE, a modular general purpose nuclear analysis code maintained at Oak Ridge National Laboratory. Several modules of SCALE have been developed for sensitivity and uncertainty analysis tasks, two of which will be used for this project: TSUNAMI and TSURFER.

SCALE: TSUNAMI

TSUNAMI (Tools for Sensitivity and Uncertainty Analysis Methodology Implementation) is a SCALE control module for the application of sensitivity and uncertainty theory to criticality safety analysis [21]. TSUNAMI computes the sensitivity of the system multiplication factor to the evaluated nuclear cross section data used to model the system. This sensitivity data is coupled with cross section covariance data to produce an uncertainty in the multiplication factor due to the underlying cross section data uncertainty. TSUNAMI is a multi-group code, and the group-wise sensitivity data it generates is stored in sensitivity data files for use with other SCALE sensitivity and uncertainty modules.

TSUNAMI features automated, problem-dependent cross section processing utilizing sensitivity versions of the standard processing codes used in SCALE. These sensitivity processing codes compute resonance-shielded cross sections and their sensitivities to the input data, which are stored as "implicit sensitivities." After cross section processing, TSUNAMI utilizes either KENO V.a or KENO-VI as Monte Carlo transport calculators to perform two criticality calculations, one forward and one adjoint. Finally, the SCALE module SAMS calculates the sensitivity coefficients that indicate the sensitivity of the calculated value of k_{eff} to changes in the cross section data as well as the uncertainty in the calculated k_{eff} due to the uncertainties in the cross section data. These sensitivity coefficients are then stored for later use.

A generalized flow diagram for TSUNAMI is given below in figure 12, outlining the various SCALE modules called and their ordering.

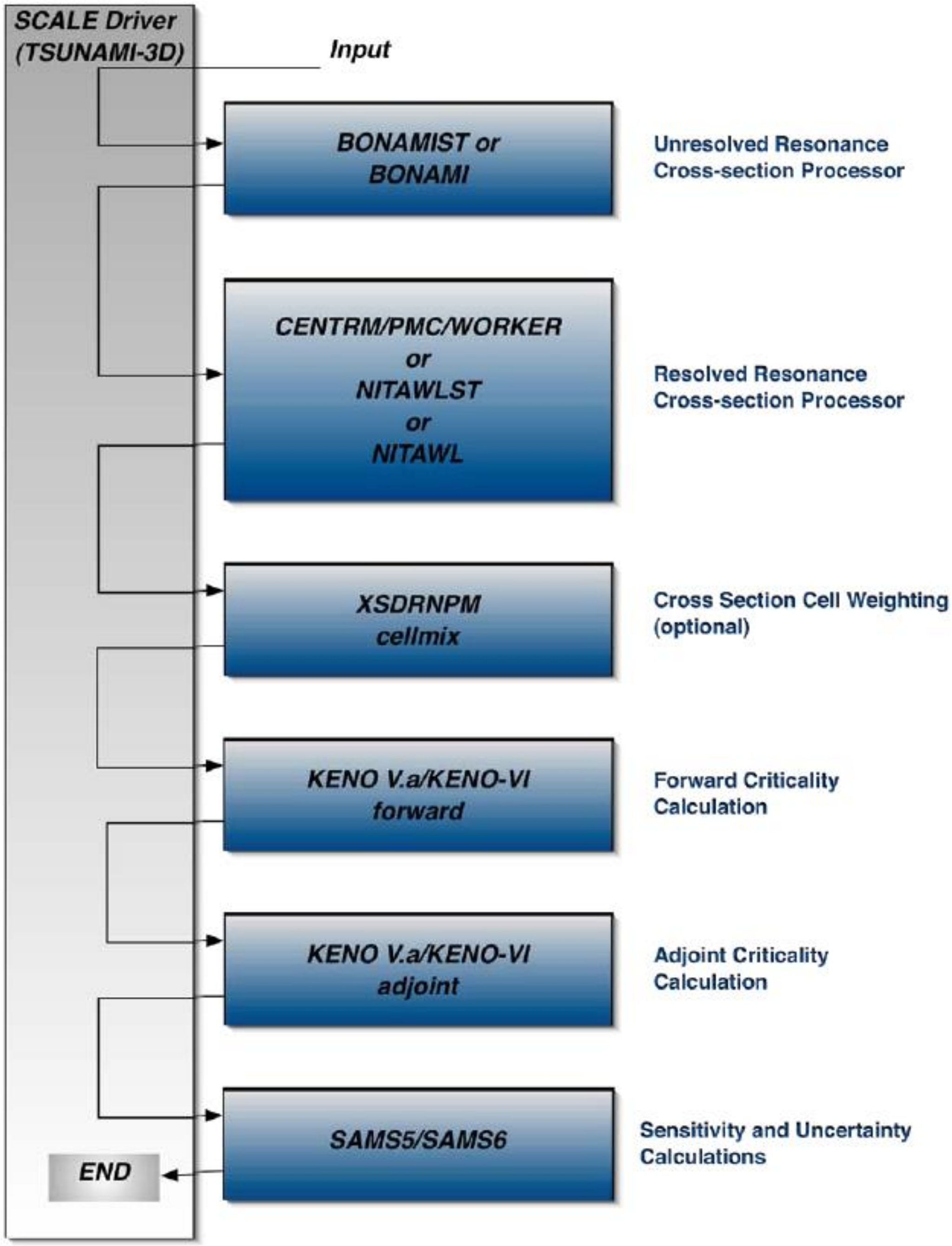

Figure 12) General Flow Diagram for TSUNAMI

SCALE: TSURFER

TSURFER (Tool for Sensitivity/Uncertainty analysis of Response Functionals using Experimental Results) is a module of SCALE responsible for computing uncertainties in integral system parameters, primarily multiplication factor, due to uncertainties in the cross section data used to model the system [22]. Additionally, TSURFER can be used to reduce discrepancies between experimentally measured integral system parameters and calculated system parameters by adjusting the nuclear data such that the overall consistency is maximized. Finally, TSURFER can analyze measured responses from benchmark experiments and establish bias and associated uncertainty in calculated application responses.

TSURFER utilizes a generalized linear least-squares (GLLS) methodology. GLLS is an application of Bayes Theorem from probability theory: if the original sets of calculated and experimental responses are consistently consolidated, taking uncertainties into account, then the "adjusted" results should be a better estimate for the true response, as the revised response is based on more information than either the original calculation or original measurement.

At the core of any nuclear system modeling is cross section data derived from fundamentally evaluated nuclear data files such as ENDF, JEFF, or JENDL. However, the "true" values of this cross section data is unknown, therefore it is reasonable to view this evaluated data as being drawn from a probability distribution of allowable values. This distribution is defined by the cross section uncertainty, as recorded in covariance data. GLLS methodology considers potential variations in cross section data and experimentally measured system parameters which minimize the differences between measured and calculated integral responses, such as k_{eff}. Such a problem is significantly underdetermined, as there exist far more cross section values than integral responses; data variations must be constrained to avoid unphysical results. TSURFER accomplishes this by constraining data adjustments in the GLLS methodology by the cross section covariance data. The result is a “best estimate” within the limits of GLLS approximations for reasonable data adjustments which improve the computed integral responses.

TSURFER defines two types of responses: experiment responses and application responses. An experiment response has both a calculated and measured integral value associated with it. An example would be a critical experiment with both a reported experimental multiplication factor, as well as a calculated multiplication factor from a modeling simulation. An application response has only a calculated integral value. Applications typically correspond to hypothetical or proposed systems considered in the context of a design study for which the computational bias and uncertainty associated with cross section uncertainty is desired. An application plays a passive role in the GLLS methodology, as it has no experimental results it does not impact the active experiment responses included the consolidation process. However, if the application response shares nuclear cross section data sensitivities with the experimental responses, it will be affected by the same data adjustments that impact the experiment responses. This provides a systematic, well defined method for utilizing benchmark measurements to establish bias and uncertainty estimates arising from nuclear data uncertainty in the calculation of system parameters in proposed nuclear system designs.

Using TSUNAMI, sensitivity profiles will be generated for both the existing molybdenum sensitive critical experiments and the proposed U(19.5%)-10Mo critical experiment designs. Using these sensitivity profiles, TSURFER will the establish bias and uncertainty estimates for the proposed critical experiment designs using both the current low fidelity molybdenum covariance data and the newly produced high fidelity molybdenum covariance data. The resulting bias estimates from the two covariance data libraries will provide a means of comparing their impact.

Chapter 3: Critical Experiment Designs

Currently few critical experiments sensitive to molybdenum exist. In particular there is a lack of thermal spectrum critical experiments. The majority of the current critical experiment library sensitive to molybdenum features either high enriched uranium molybdenum alloy fuel in a fast spectrum, or molybdenum only as structural or reflector material. As the research and test reactors which will utilize the new low enriched U-Moly foil fuel form feature thermal spectra, such as the ATR at Idaho National Lab, experiments addressing this lack of thermal spectrum data are necessary. This chapter presents two fast spectrum experiment concepts as well as two thermal spectrum experiment concepts to be carried out at the National Criticality Experiments Research Center. The two fast spectrum experiment designs are referred to as the Fast Bare Critical Experiment and Fast Reflected Critical Experiment, while the two thermal spectrum experiment designs are referred to as the Thermal Standard Molybdenum Critical Experiment and the Thermal Maximum Molybdenum Critical Experiment.

Comparisons of the fast and thermal spectra critical experiments should provide additional insight into uncertainty in the molybdenum isotope cross-sections data. In particular, while the thermal spectrum experiment may exhibit greater overall sensitivity to the molybdenum cross-sections due to the higher neutron populations at low energies, the molybdenum cross-sections themselves are presently more uncertain in the resolved and unresolved resonance energy regions. This series of critical experiments would establish critical masses of the low enriched U-Moly foil fuel form, both in highly thermalized and fast neutron spectra. Comparisons of the experimental critical mass to computational models may indicate needed corrections to molybdenum cross-section data.

Of the experimental machines available for criticality experimentation at the National Criticality Experiments Research Center (NCERC) in Nevada, the most useful for this type of experiment will be the large capacity vertical lift table known as Comet, shown below in figure 13 [23].

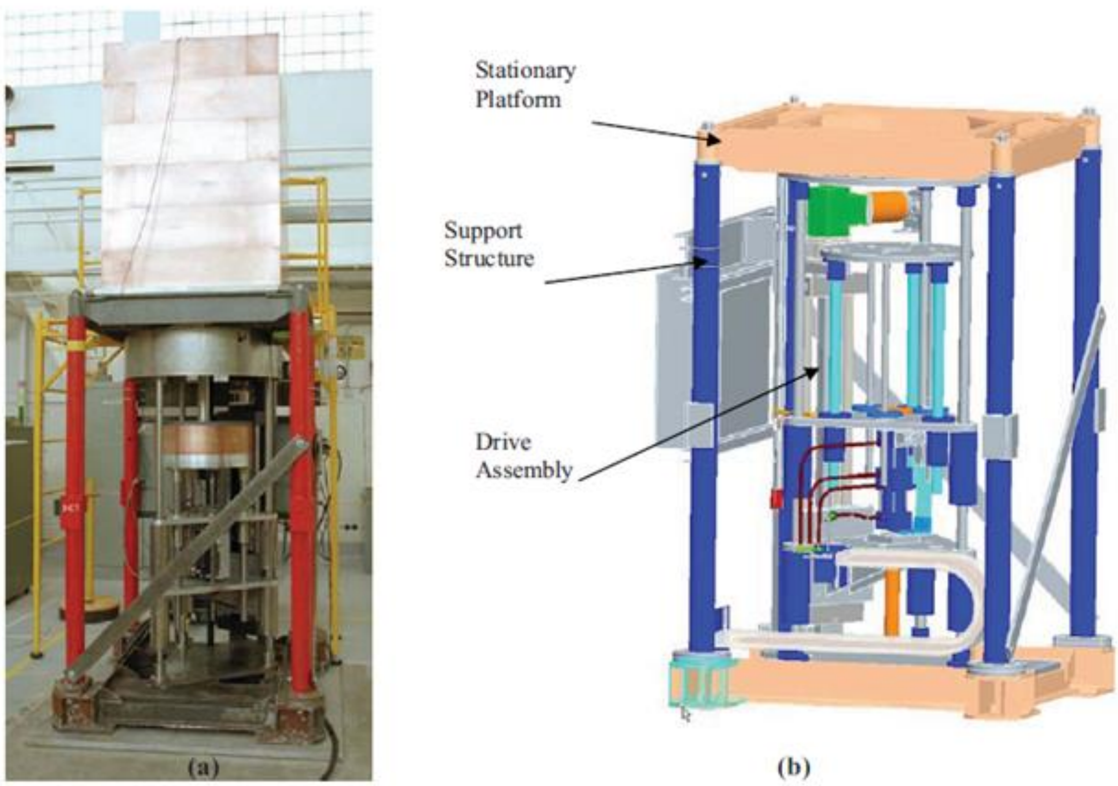

Figure 13) Comet Vertical Split Table Test Device

The substantially increased capacity of Comet as compared to the other vertical lift table available will be required as moderating and reflecting material will be included in the some of the experimental designs. [24]

The general initial experimental set up is as follows: two subcritical assemblies would be constructed from either thick layers of U-Mo fuel foils and HEU in the case of the fast spectrum designs, or from interlayed fuel foils and moderating material in the case of the thermal spectrum designs. [25] A graphite reflector would surround the two subcritial assemblies on five sides in the case of the Fast Reflected experiment and both thermal spectrum experiments. These two assemblies would then be brought together using the Comet lifting table as shown below in figure 14.

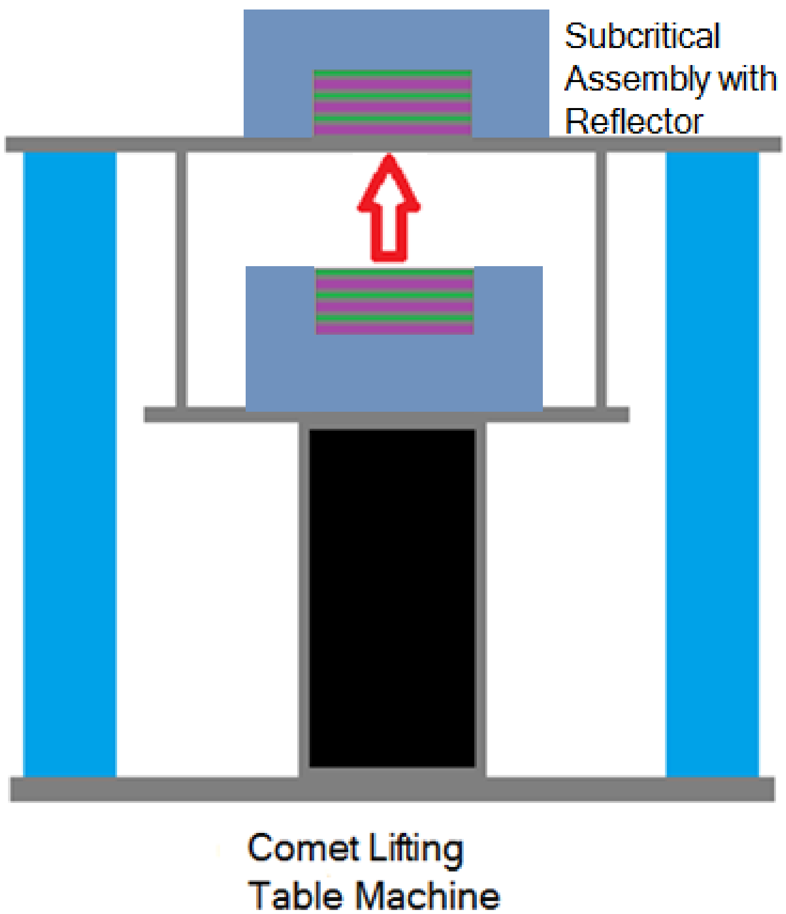

Figure 14) Proposed Experimental Set Up

Initial Scoping Studies and Existing Critical Experiments

Prior to beginning the critical experiment design process, it was desired to determine the effects molybdenum isotope cross section differences could have on integral system parameters, such as multiplication factor. As a first look, an infinite media case of a U(19.5%)-10Mo metal fuel was modeled using MCNP5 [26]. The simulation was repeated with the molybdenum isotope cross section data provided by three different data libraries: ENDF-B/VII.1, JEFF 3.1.1, and JENDL 4.0, results shown in table 11.

Table 11) Multiplication Factors for Infinite Metal

Library	k_{eff}	MCNP Standard Deviation
ENDF-B/VII.1	1.56929	0.00023
JEFF3.1.1	1.56997	0.00023
JENDL4.0	1.57279	0.00024

The differences in k_{eff} is equivalent to a change of 43.313 pcm when comparing ENDF to JEFF data, 222.535 pcm when comparing ENDF to JENDL data, and 179.299 pcm when comparing JENDL to JEFF data. These differences are not insignificant, particularly in the case of JENDL data.

The hypothetical infinite homogenous metal case modeled above would result in a fast neutron spectrum, as no moderator is present. As high energy neutrons dominate the response of this system, the multiplication factor will be sensitive to differences in the high energy cross-section of the molybdenum isotopes between libraries, while differences at lower energies in the resonance region and below will likely be of minimal effect. Therefore the above process was repeated for an infinite repeating square lattice of cylindrical metal fuel pins, surrounded by light water moderator. The fuel pin radius was 0.6 cm, with a pitch of 5.65 cm, as shown in figure 15. The resulting calculated multiplication factors are given in table 12.

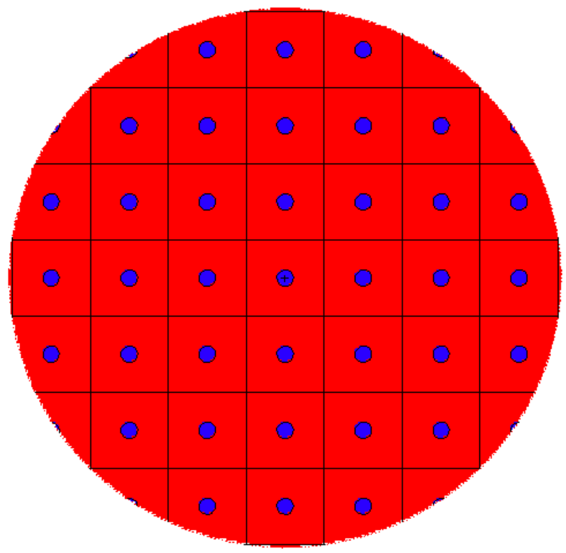

Figure 15) Infinite Lattice of Cylindrical U(19.5%)-10Mo Fuel Elements

Table 12) Multiplication Factors for Infinite Square Lattice

Library	k_{eff}	MCNP Standard Deviation
ENDF-B/VII.1	1.00338	0.00031
JEFF3.1.1	1.00350	0.00031
JENDL4.0	1.00417	0.00030

The differences in k_{eff} is equivalent to a change of 11.958 pcm when comparing ENDF to JEFF data, 78.672 pcm when comparing ENDF to JENDL data, and 66.722 pcm when comparing JENDL to JEFF data. These results show significantly less difference than in the infinite unmoderated case. This indicates that differences in the low energy and resonance regions of the molybdenum cross-sections between the three libraries may be less pronounced than those in the high energy region, or that the system is less sensitive to those changes.

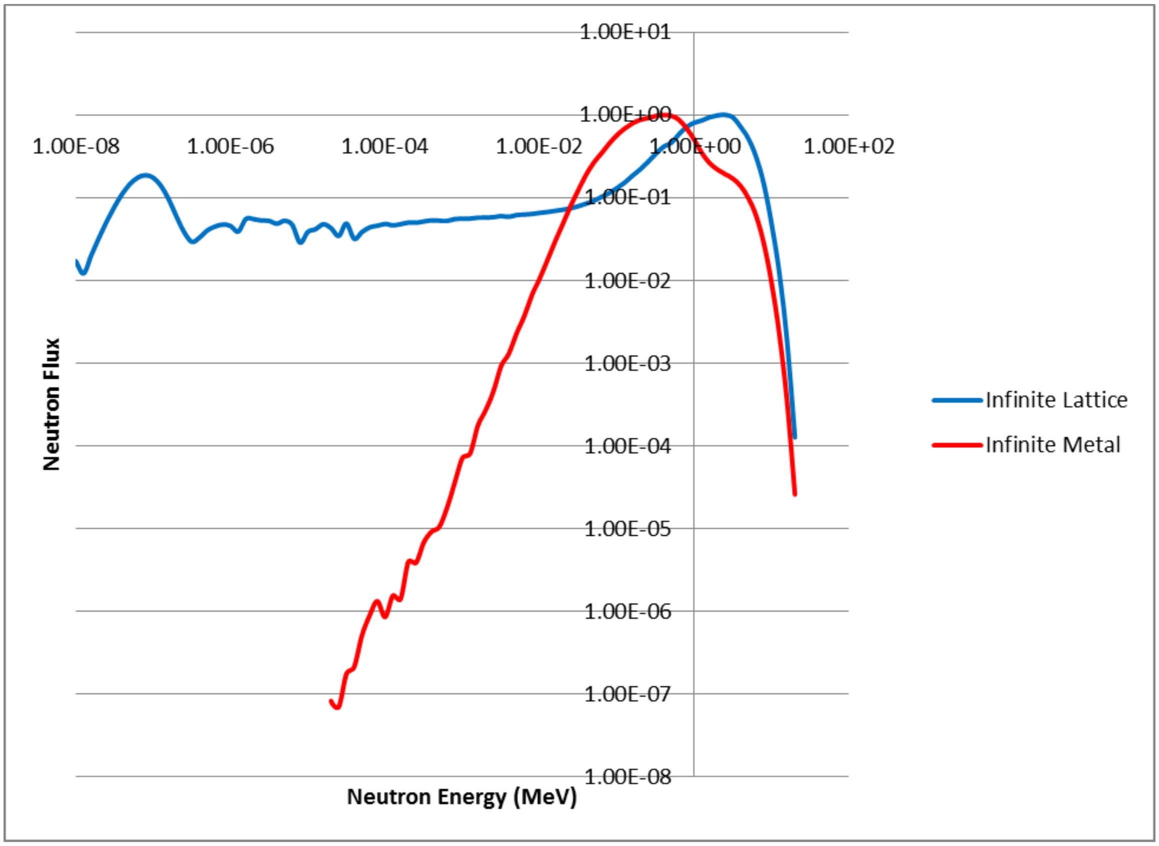

Figure 16) Spectra for Infinite Metal and Infinite Moderated Lattice of U-10Moly Fuel

Figure 16 above shows the calculated flux spectra for the infinite homogenous U-Moly metal and an infinite lattice of U-Moly fuel pins surrounded by light water, normalized by the peak channel for each. For the infinite homogeneous metal case, there is no appreciable thermal flux, as expected. The critical infinite lattice of U-Moly fuel pins exhibits a well moderated spectrum.

In order to determine the fuel/moderator volume ratio that would result in the largest difference in multiplication factor between data libraries, the infinite lattice model used previously was used again, varying the ratio of fuel area to moderator area in the lattice unit cell. Figure 17 below shows the absolute value of the difference in multiplication factor, in pcm, between data libraries, versus the fuel/moderator ratio over a range of 0.05 to 0.60.

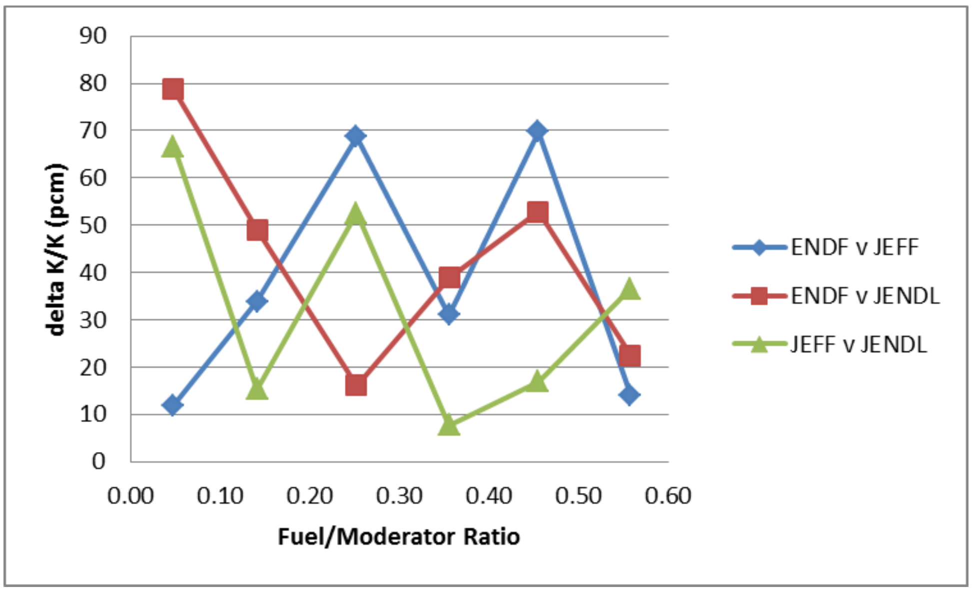

Figure 17) Delta K/K vs. Fuel/Moderator Ratio

No clear pattern emerged over this range of ratio values. This suggests that cross section differences across a wide range of energies are contributing to the disagreement in multiplication factor. The ratio with the greatest average difference in multiplication factor was around 0.05.

ORNL Fast Burst Reactor Critical Experiments

Critical experiment benchmarks are required in order to compare the computational results associated with each library to a known experimental result. Molybdenum can often be found in structural materials, and reflectors; but experimental data of uranium-molybdenum alloy fuels are rare.

However, there are technical reports from a series of critical experiments completed in the early 1960s with the ORNL Fast Burst Reactor, later renamed the Health Physics Research Reactor, as well as critical experiments dating to the design phase for that reactor.

The critical experiments associated with the design of the HPRR are likely to be more relevant for the purposes of this research. In these experiments a series of four critical assemblies of differing cylindrical and annular geometries were studied. The technical reports for these experiments include material compositions and experimentally verified critical dimensions, generally cylinder or annulus heights. However, some aspects of the experiment were approximated. These critical experiments will serve as a basis for cross section and covariance data comparison [27].

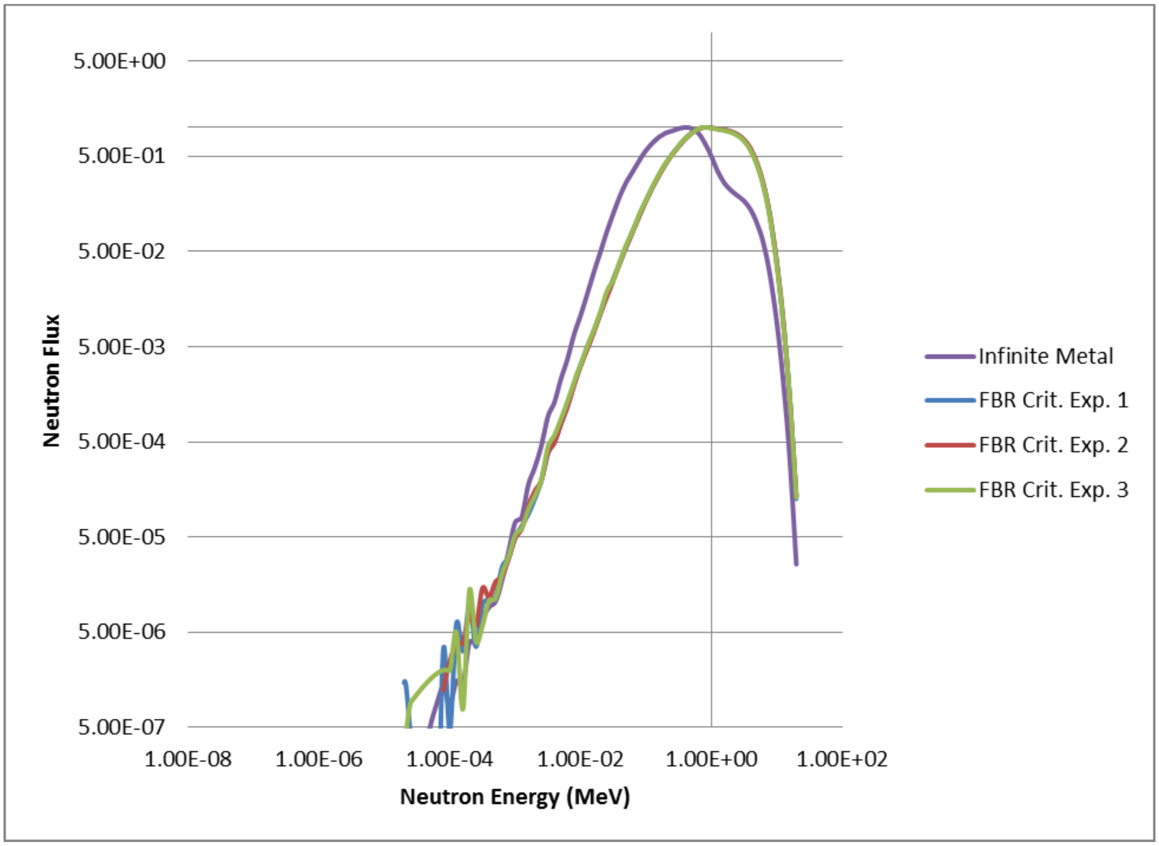

Figure 18) Spectra of three bare unmoderated FBR critical experiments

Three unreflected criticality experiments were modeled as follows: (1) a solid cylinder 14.78 cm high of U(93%)-10Mo alloy, 20.38 cm diameter; (2) an annulus 19.74 cm high with a 5.08 cm inner diameter, and (3) an annulus 18.92 cm high with a 5.08 cm diameter 304 steel core. Each experiment was modeled in MCNP with ENDF/B-VII.1, JEFF3.1.1, and JENDL4.0 cross-section data. Figure 18 above gives the calculated neutron spectra for these three experiments compared to the spectra of the homogeneous infinite metal modeled before. For each case in figure 18 the spectrum is normalized by the maximum channel value.

The experiments have an even faster spectrum than the infinite metal due to neutron leakage. Change in multiplication factor due to the different libraries was calculated in pcm. These results are given in table 13.

Table 13) FBR Crit. Experiment #1, #2, and #3

	ORNL FBR Crit. Exp. #1		ORNL FBR Crit. Exp. #2		ORNL FBR Crit. Exp. #3	
	K-eff		*K-eff*		*K-eff*	
ENDF	0.9961		0.99391		0.99670	
JEFF	0.9966		0.99422		0.99653	
JENDL	0.9972		0.99481		0.99703	
	del K/K	*pcm*	*del K/K*	*pcm*	*del K/K*	*pcm*
ENDF vs JEFF	0.000512	51.17399	0.000312	31.18022	-0.00017	-17.059
ENDF vs JENDL	0.001113	111.3117	0.000905	90.46954	0.000331	33.098
JENDL vs JEFF	0.000602	60.16847	0.000593	59.30781	0.000501	50.149

On average the disagreement between molybdenum libraries was between 50 and 60 pcm. Changes to the molybdenum cross-sections therefore have substantial impacts on the multiplication factor of systems using uranium-molybdenum fuel. The next step would be to determine more specifically which cross-sections and energy regions are responsible for those impacts.

The TSUNAMI module of the SCALE code package calculates sensitivity of multiplication factor to material cross-section data. TSUNAMI is a neutron transport eigenvalue sensitivity analysis sequence using adjoint based first order perturbation theory [27]. The geometries for the three fast critical experiments were very simple, and they were modeled using the 3-D version of the TSUNAMI code.

Figure 19 below show the total sensitivity for each isotope for critical experiment #1, obtained by varying the total cross-section in each lethargy bin and then dividing the resulting change in multiplication factor by the width of the bin in lethargy. This total sensitivity is analogous to sensitivity of the system to the atomic density of each isotope, and in turn the cross-section data of that isotope. Sensitivity for critical experiments 2 and 3 are very similar to figure 19.

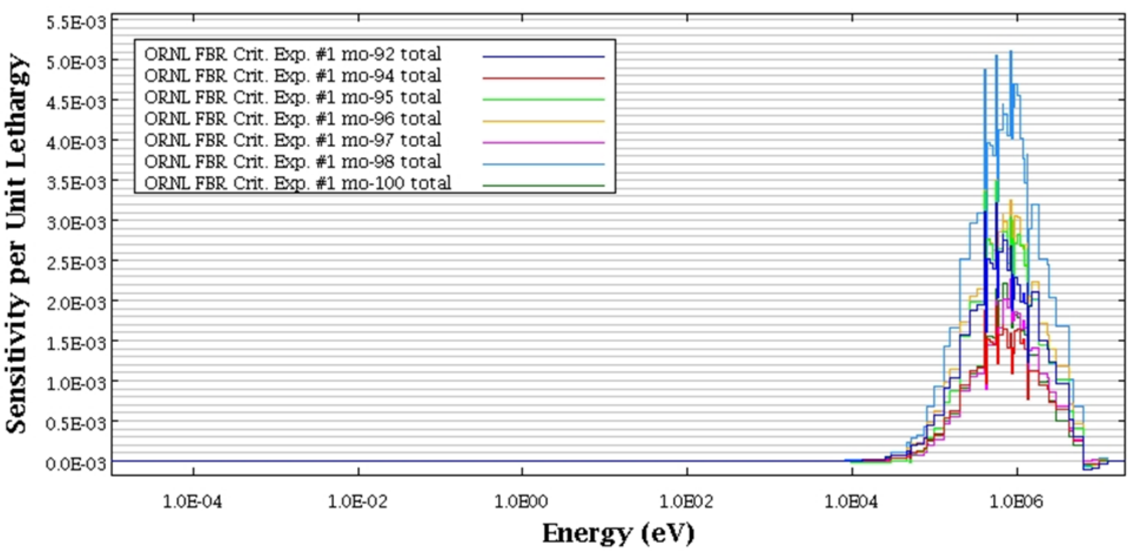

Figure 19) Total Sensitivity vs. Energy for Molybdenum Isotopes in ORNL FBR Crit. Experiment #1

As expected, due to the spectra of these experiments, the sensitivity is entirely in the high energy region, as this is the only energy region populated by neutrons in these experiments. In particular, the systems are most sensitive to ^{92}Mo, ^{95}Mo, ^{96}Mo, and ^{98}Mo. However, these experiments may miss sensitivities arising from differences in the resonance region, where significant discrepancies between cross-section libraries have already been seen. Therefore it is necessary to model systems having a more thermalized spectrum, with neutron population in the resonance energy region.

In addition to the experimental systems detailed thus far, several critical experiments were also conducted which included plexiglass reflectors. Plexiglass has a high atomic density of hydrogen and carbon, and serves as moderator in addition to reflecting neutrons [28]. ORNL FBR Critical Experiment #4 was an annulus of high enriched U-Mo which was reflected by 5.08 cm of plexiglass on external surfaces, but void in the central region. ORNL FBR Critical Experiment # 5 was a similar annulus, reflected by 2.54 cm of plexiglass on external surfaces, but with additional plexiglass filling the inner void as well.

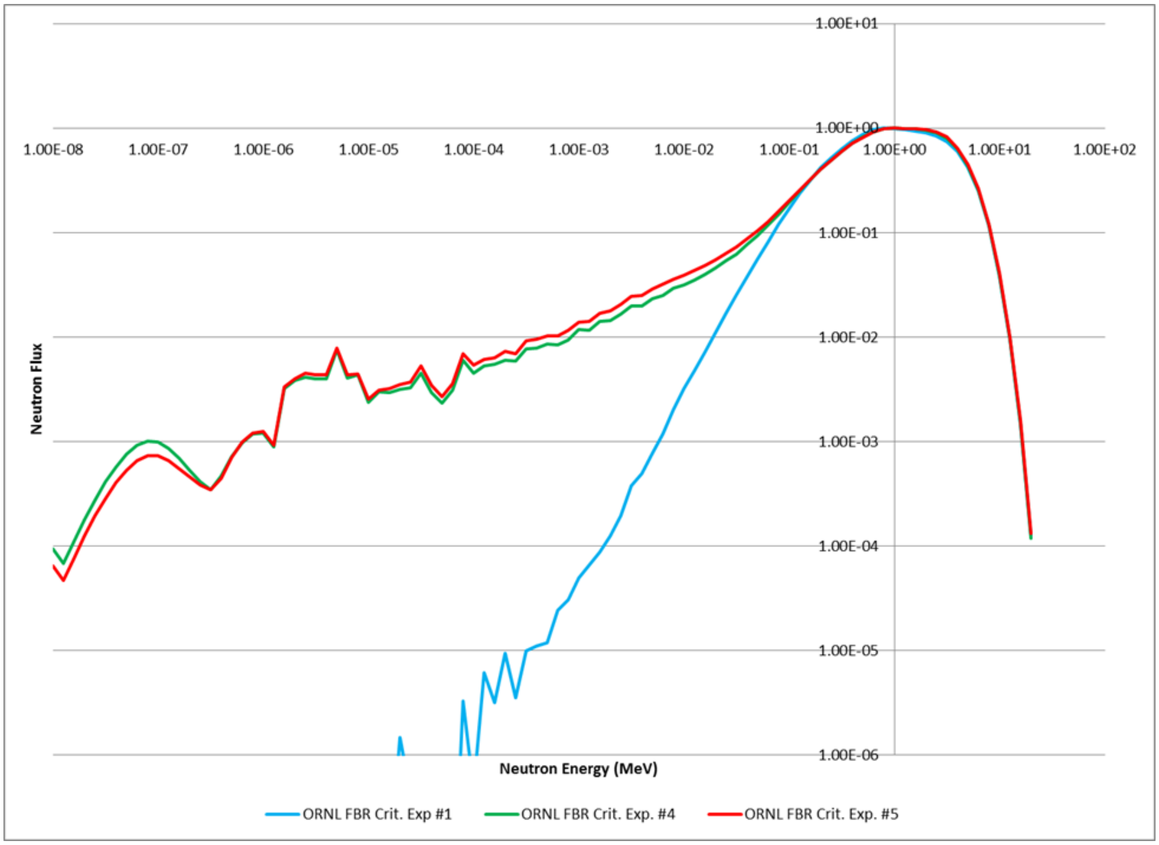

Figure 20) Flux Spectra for ORNL FBR Crit. Exps. #1, #4, and #5

The above figure 20 shows the MCNP calculated flux spectra for three of the FBR critical experiments, normalized by peak channel value. FBR Crit. Exp. #1 was a bare cylinder of high enriched U-Mo metal, as has been shown previously. For the bare homogeneous metal case, there is no appreciable thermal flux, as expected. The two reflected critical experiments demonstrate moderated spectra. In particular, ORNL FBR Crit. Exp. #4 exhibits the most thermalized neutron spectrum of all the U-Mo alloy fueled critical experiments to date.

The two reflected criticality experiments were modeled as follows: (1) an annulus 12.57 cm high, 20.38 cm diameter with an 8.89 cm inner diameter, reflected on all external surfaces by 5.08 cm of plexiglass; (2) an annulus 13.86 cm high with a 8.89 cm inner diameter for the lower 12.7 cm height, and 5.08 cm inner diameter for the remainder, with 2.54 cm of plexiglass on all external surfaces, and plexiglass in the central void as well. Each experiment was modeled in MCNP with ENDF/B-VII.1, JEFF3.1.1, and JENDL4.0 cross-section data for the molybdenum isotopes. Change in k-eff due to the different libraries was calculated in pcm. These results are given in table 14.

Table 14) FBR Crit. Experiment #4 and #5

	ORNL FBR Crit. Exp. #4		**ORNL FBR Crit. Exp #5**	
	K-eff		*K-eff*	
ENDF	1.00999		1.00928	
JEFF	1.00987		1.01020	
JENDL	1.01076		1.00935	
	del K/K	*pcm*	*del K/K*	*pcm*
ENDF vs JEFF	-0.00012	-11.8827	0.000911	91.07108
ENDF vs JENDL	0.000762	76.1803	6.94E-05	6.935156
JENDL vs JEFF	0.000881	88.05255	-0.00084	-84.2126

The thermal spectrum experiments exhibit increased reactivity changes as compared to the fast spectrum experiments described previously, on average there is 70-80 pcm difference between libraries.

TSUNAMI was again used to compute sensitivities for the molybdenum isotopes in the more thermalized spectra of FBR critical experiment #4 and #5. Plots of the total sensitivities of the molybdenum isotopes are given below in figures 21 and 22. Again the majority of sensitivity is in the high energy region. However, unlike the sensitivity plots for the bare critical experiments, sensitivity responses in the resonance region are present;

including large responses due to resonances of ^{95}Mo and ^{97}Mo. The effects of these resonances may account for the previous computational results in which no clear pattern of change in k_{eff} was found in relation to fuel to moderator ratio.

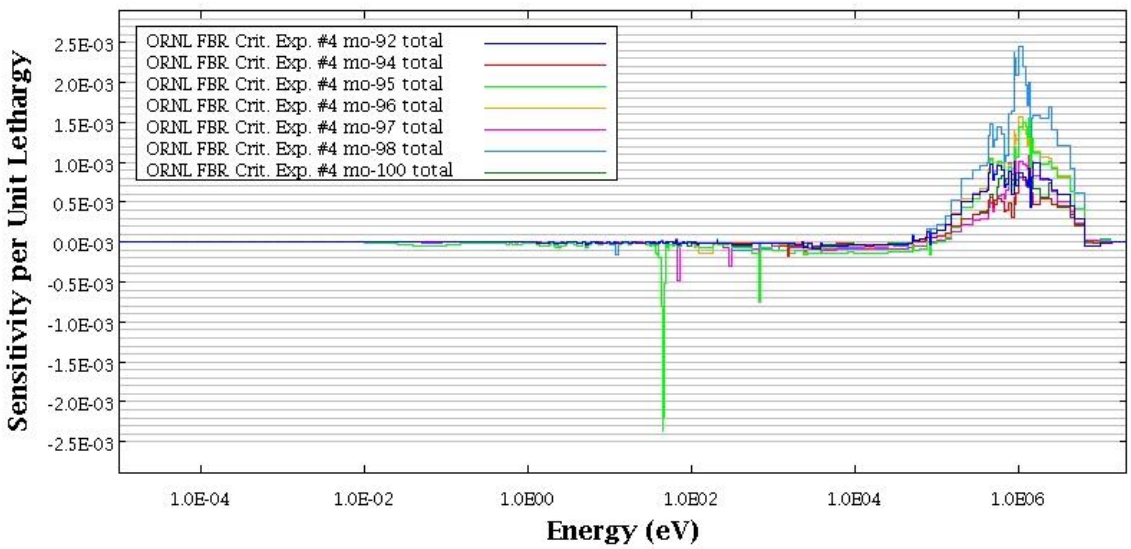

Figure 21) Total Sensitivity vs. Energy for Molybdenum Isotopes in ORNL FBR Crit. Experiment #4

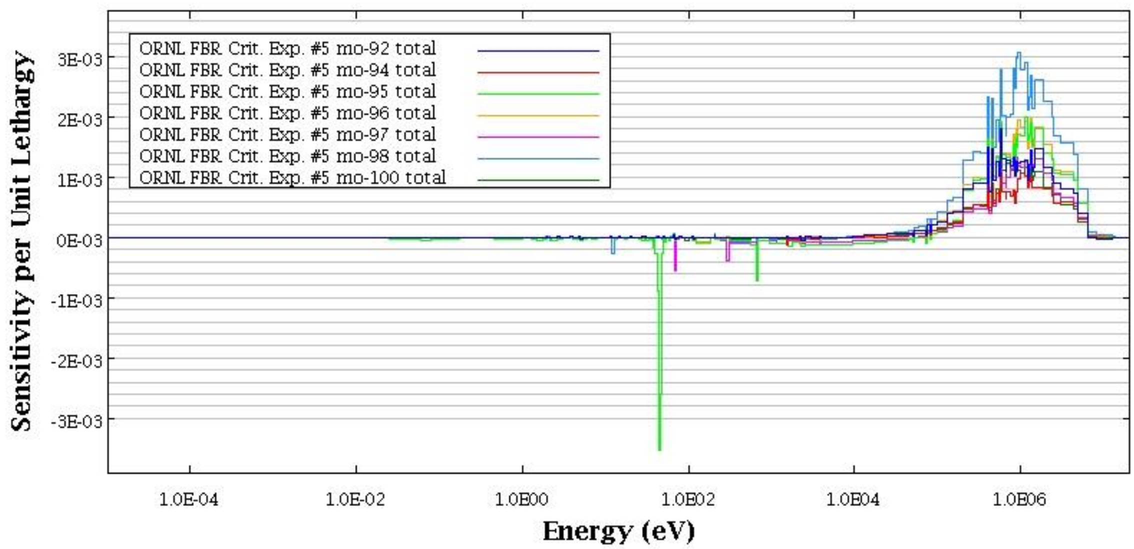

Figure 22) Total Sensitivity vs. Energy for Molybdenum Isotopes in ORNL FBR Crit. Experiment #5

Breaking down the total uncertainty per isotope, TSUNAMI also demonstrates which reaction cross-sections the system multiplication factor is most sensitive to. In the case of molybdenum in these criticality experiments, the high energy sensitivity is due to the neutron scattering cross-sections of the molybdenum isotopes at those energies, while the large spikes in sensitivity in the resonance regions are due to the neutron capture cross-section of specific isotopes, ^{95}Mo and ^{97}Mo. Conceivably, if these cross-sections were altered based on the sensitivity of the experimental systems to these cross-sections, the computed system parameters, such as multiplication factor, could be made to conform more closely to the reported experimental system parameters. This would again verify the effect on the system due to molybdenum cross-section uncertainty. A module exists in the SCALE code package to calculate just such cross-section changes.

The TSURFER module of SCALE allows for the calculation of computational biases, deriving largely from cross-section data uncertainty, using a generalized linear least squares approach. TSURFER identifies a single set of adjustments to nuclear data that will result in the computational models all producing k_{eff} values close to their experimental k_{eff} value The difference between the originally calculated k_{eff} value and the new post-adjustment k_{eff} value represents the bias in the original calculation, and the uncertainty in the adjusted value represents the uncertainty in this bias [29]. Sensitivity profiles generated by the TSUNAMI module of SCALE for the systems in question are used, while the provided covariance library determines the boundaries for changes to the cross-section data. The sensitivity profiles used were generated using ENDF/B-VII.0 cross section data for all isotopes. The currently available low fidelity molybdenum covariance library was used.

Two sets of critical experiments were utilized:

1) The five critical experiments using high enriched U-Mo fuel performed at ORNL and previously discussed at length.
2) The above, as well as all other experiments from the ICSBEP which include molybdenum, typically as either a reflector or structural material.

For consistency, chi squared values of 0.8-1.2 are recommended. In the context of TSURFER, chi squared is the standard deviation of the nuclear data and measured integral responses. In order to ensure the target chi-square value, TSURFER eliminates experiments from the set of considered experiments until the value of chi-squared per degree of freedom is below the desired threshold.

Set 1: ORNL FBR critical experiments

1.2 Chi-squared

With the recommended constraint on chi-squared three of the five FBR criticality experiments were eliminated from consideration, leaving the two plexiglass moderated experiments. The multiplication factor of these experiments was most sensitive to ^{92}Mo and ^{98}Mo, plots of the TSURFER calculated cross-section adjustments for these isotopes are given below in figure 23 and 24.

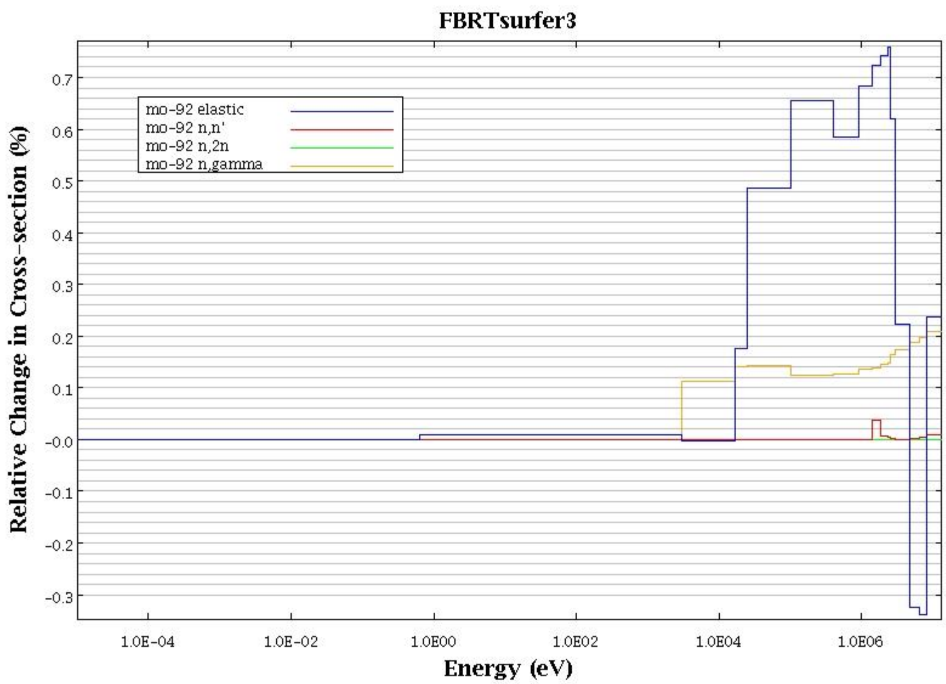

Figure 23) ^{92}Mo Cross Section Adjustments for Set 1, 1.2 Chi-squared

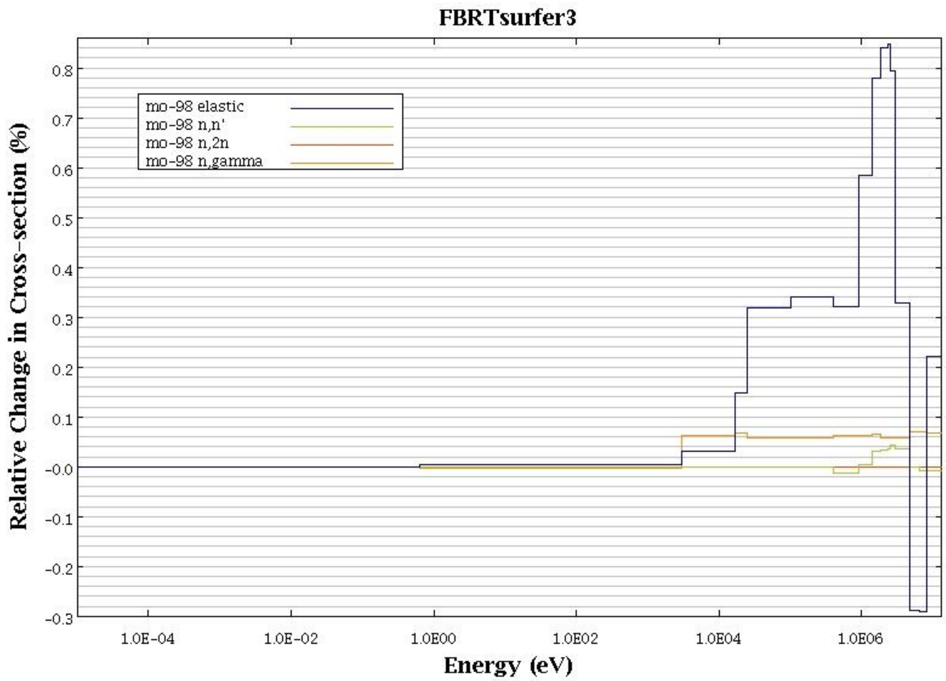

Figure 24) ^{98}Mo Cross Section Adjustments for Set 1, 1.2 Chi-squared

The largest cross-sections changes are for high energy elastic scattering. Figure 25 below shows the elastic cross-section changes for all molybdenum isotopes, all of which follow a similar pattern to each other.

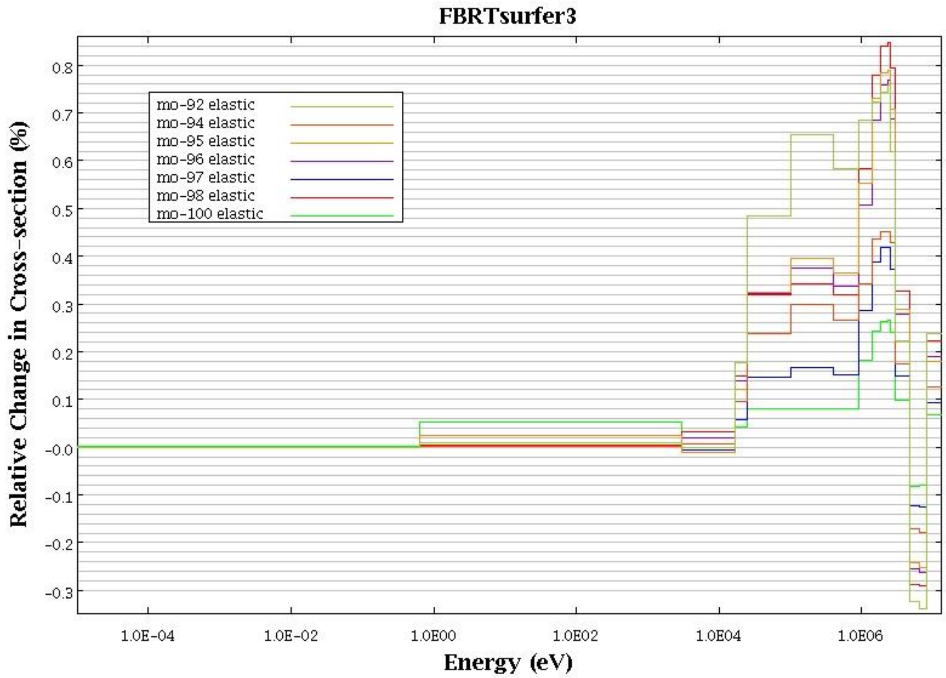

Figure 25) Molybdenum Elastic Scattering Cross Section Adjustments for Set 1, 1.2 Chi-squared

However, these changes are dwarfed by the changes in ^{235}U(n,gamma) cross section, shown in figure 26.

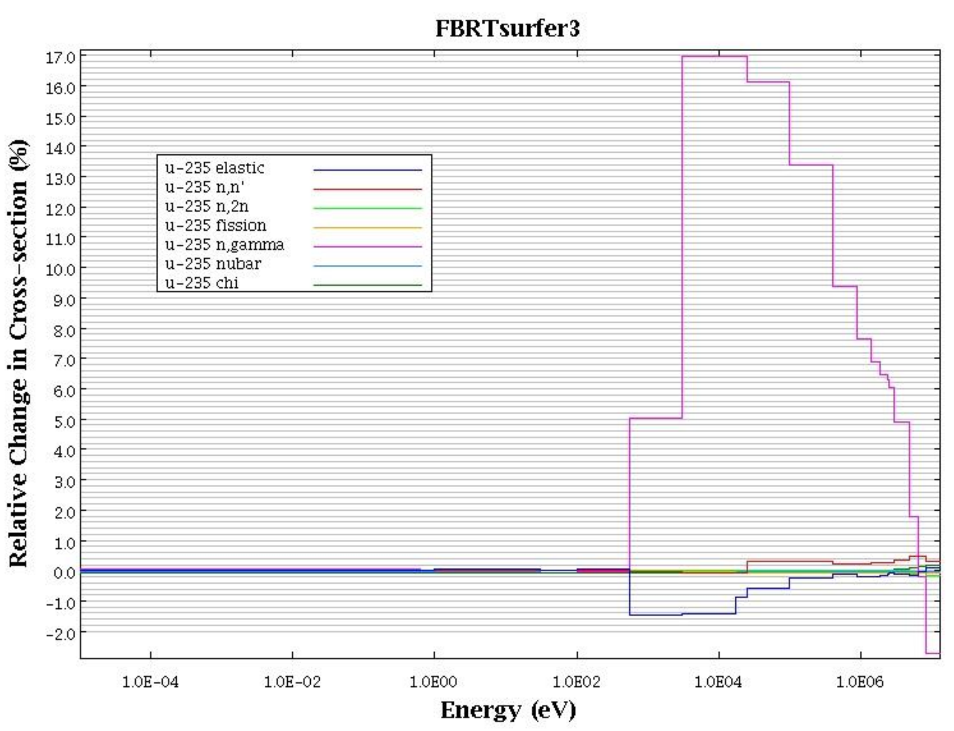

Figure 26) ^{235}U Cross Section Adjustments for Set 1, 1.2 Chi-squared

The two moderated experimental systems considered by this TSURFER run have calculated multiplication factors of around 1.007 and experimental multiplication factors of 1.000. Increased parasitic absorption by ^{235}U will therefore strongly push the calculated value closer to the experimental value. This illustrates an issue which affects nearly all sensitivity and uncertainty analysis. As seen in figure 9, currently there is extremely high uncertainty regarding the high energy neutron capture cross section of ^{235}U, uncertainty in excess of 50% throughout the high energy region. Any system using ^{235}U as the multiplying material will be extremely sensitive to this capture cross section with respect to multiplication factor. Therefore analysis such as is possible with TSURFER, featuring a consolidation of cross section adjustments to secure the best fit between experimental and computational results, will frequently produce large scale adjustments to the ^{235}U capture cross section which may "wash out" adjustments to other isotopes which this system is less sensitive too. Therefore a reduction in the uncertainty of the ^{235}U capture cross section could provide a substantial improvement in the value of such sensitivity and uncertainty analysis work.

Below are the cross-section adjustments for ^{238}U, the other primary component of the U-Mo fuel, which demonstrates relatively insignificant changes, shown in figure 27.

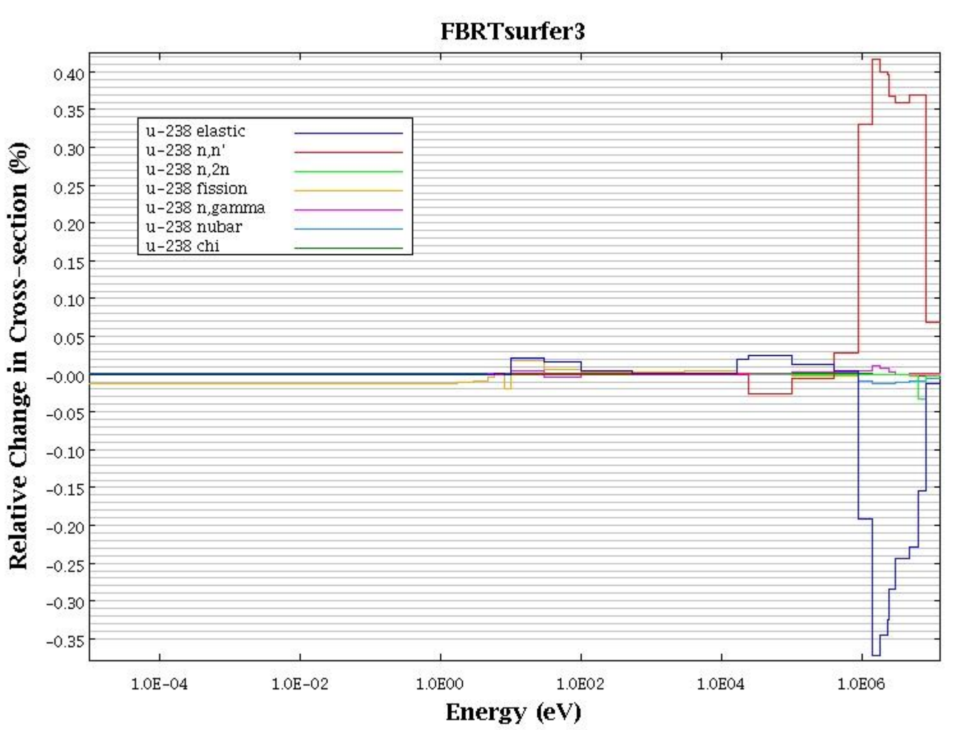

Figure 27) ^{238}U Cross Section Adjustments for Set 1, 1.2 Chi-squared

It is difficult to draw conclusions from the cross-section adjustments in figures 23 through 27, as they rely on only two experimental responses. In order to include more experimental systems sensitive to molybdenum, attention was turned to the International

Handbook of Evaluated Criticality Safety Benchmark Experiments, maintained by the International Criticality Safety Benchmark Program (ICSBEP).

Set 2: FBR critical experiments and all experiments from the ICSBEP which include molybdenum

In addition to the ORNL FBR critical experiments included for the previous set of TSURFER runs, the ICSBEP contains a further 29 experiments which include molybdenum. The molybdenum in these experiments is primarily found in reflectors or structural components.

1.2 Chi-squared

In order to achieve the desired degree of consistency, 19 of the 34 experiments were eliminated including one of the FBR critical experiments. However, the resulting cross-section adjustments, seen below in figures 28, 29 and 30, followed the same pattern of altering the high energy cross sections as for the previous experiment sets, but are roughly an order of magnitude larger than the previous set of cross section adjustments.

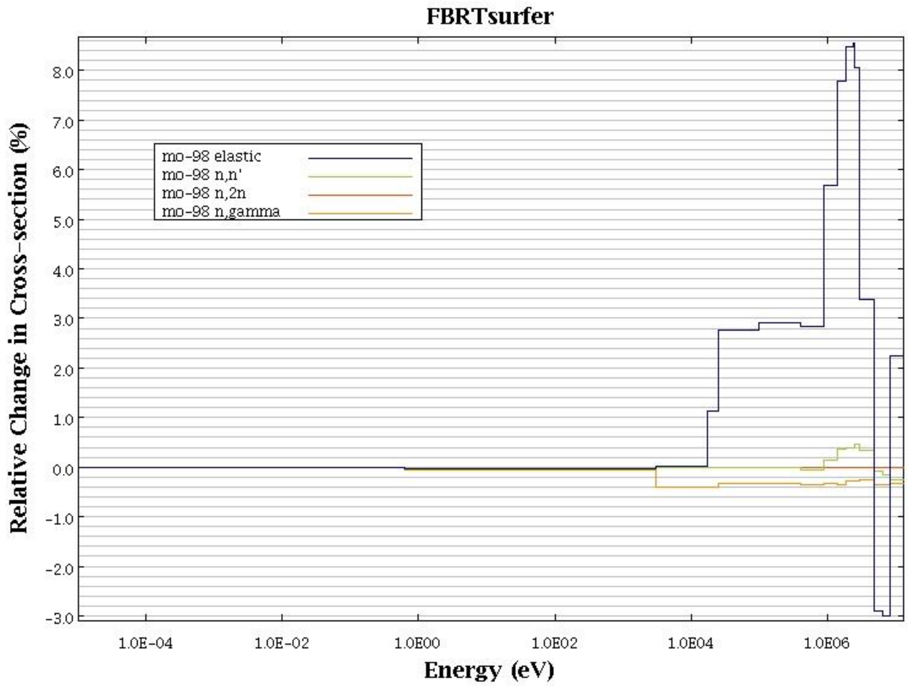

Figure 28) ^{98}Mo Cross Section Adjustments for Set 2, 1.2 Chi-squared

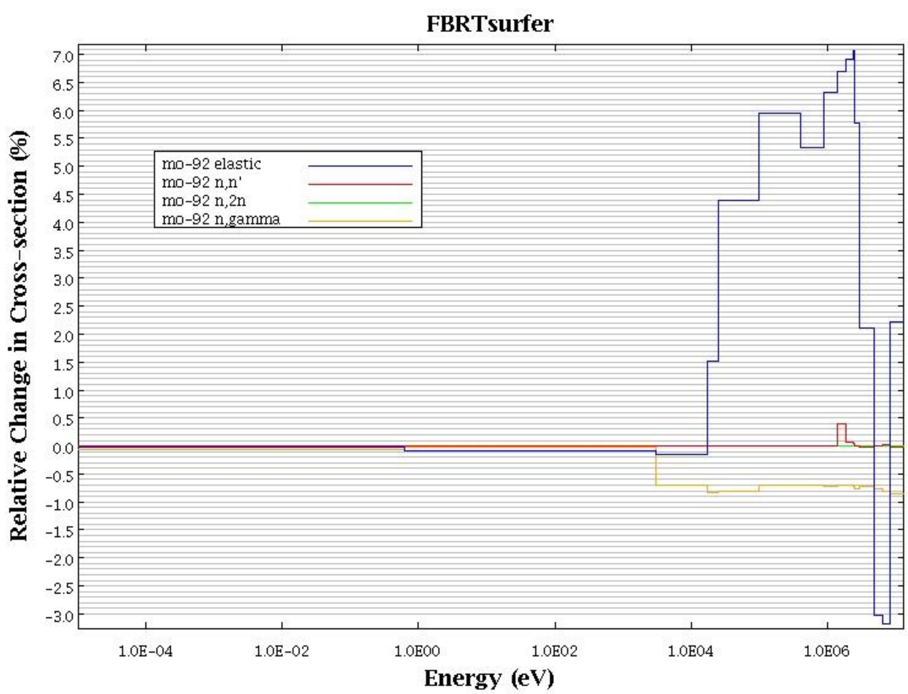

Figure 29) ^{92}Mo Cross Section Adjustments for Set 2, 1.2 Chi-squared

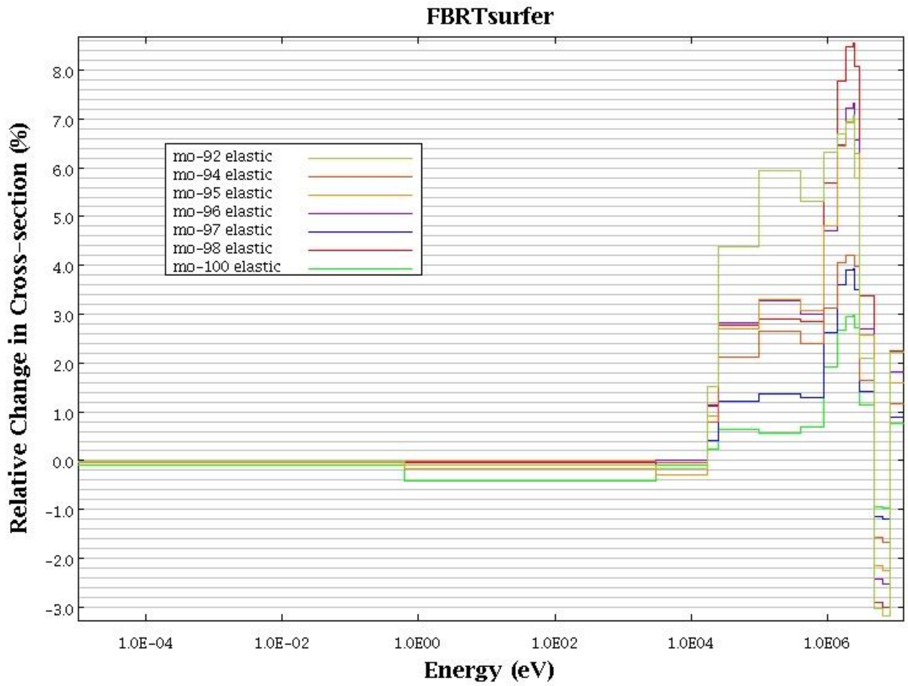

Figure 30) Molybdenum Elastic Scattering Cross Section Adjustments for Set 2, 1.2 Chi-squared

Additionally, non-negligible adjustments to the molybdenum capture cross sections are also suggested, as seen in figure 31 below. Adjustments in the resonance region are seen for ^{97}Mo, a strong resonance absorber.

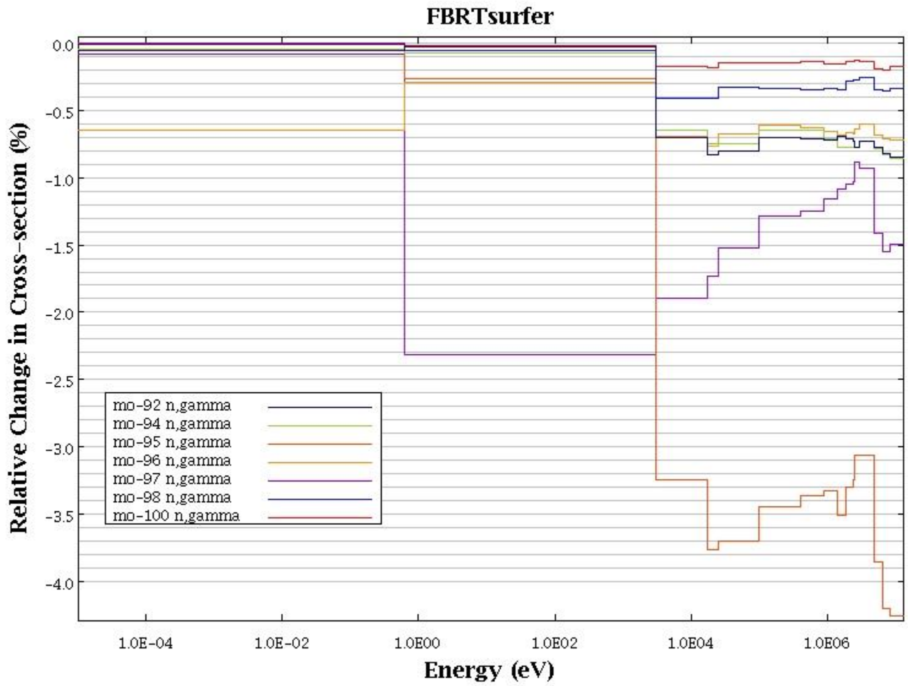

Figure 31) Molybdenum Capture Cross Section Adjustments for Set 2, 1.2 Chi-squared

Cross section adjustments for ^{235}U and ^{238}U are similar, though somewhat greater in magnitude, for the set of all molybdenum sensitive critical experiments as compared to the case of only the ORNL FBR critical experiments. They are seen below in figures 32 and 33.

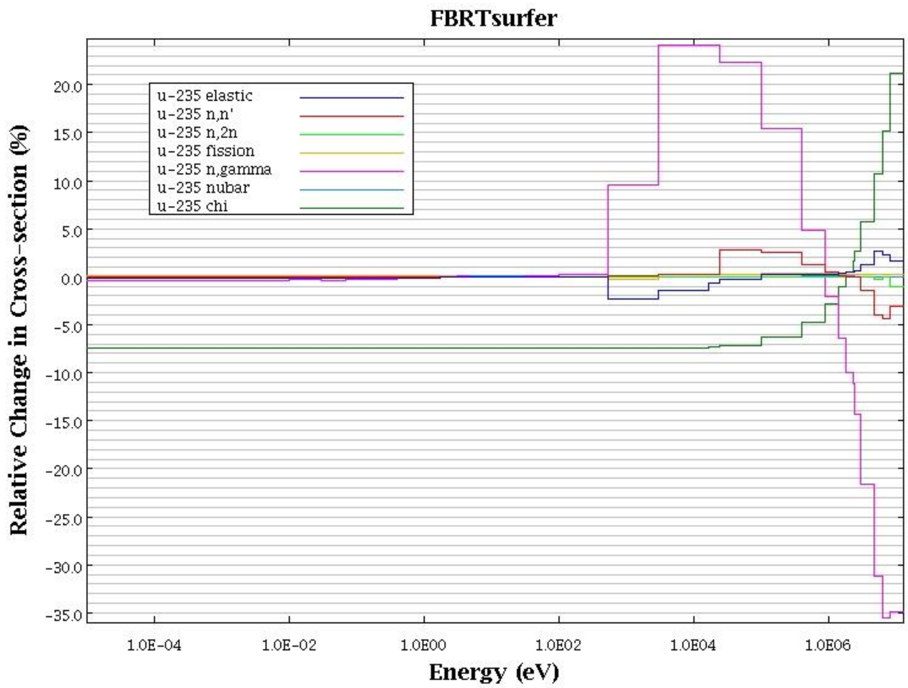

Figure 32) ^{235}U Cross Section Adjustments for Set 2, 1.2 Chi-squared

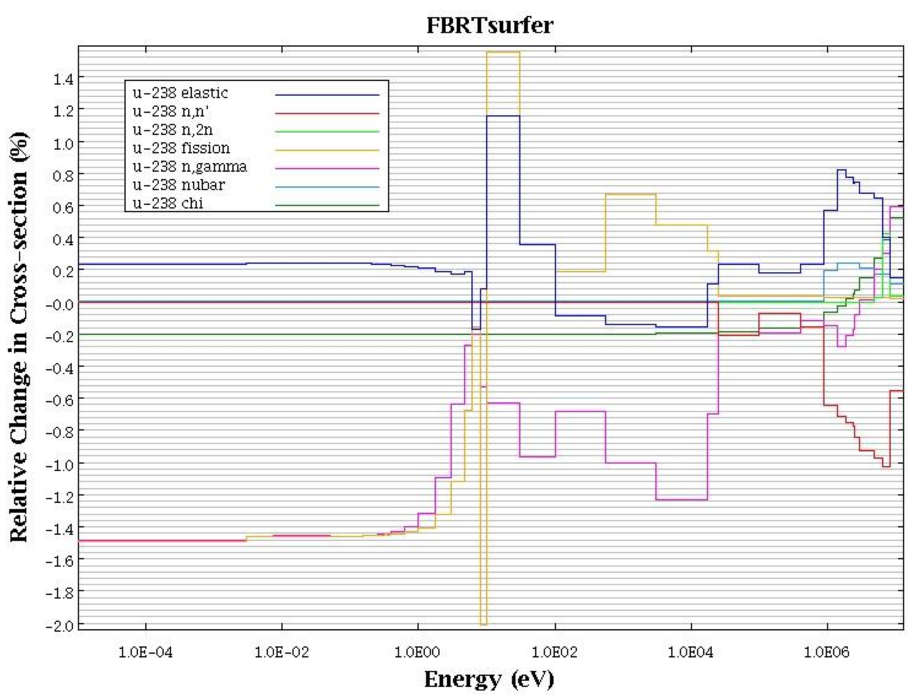

Figure 33) ^{238}U Cross Section Adjustments for Set 2, 1.2 Chi-squared

The modeling study of existing molybdenum sensitive critical experiments detailed above informed the design process of a new series of critical experiments to feature the new Y-12 U-Moly foil fuel form. Key deficiencies in the critical experiment library include most notably a lack of U-Moly fueled critical experiments with a thermal neutron spectrum.

Therefore, the series of critical experiments proposed shall include both fast and thermal spectra experiments, to fully explore uncertainty in the molybdenum cross sections throughout the energy region; while also providing valuable characterization of the new fuel form.

PROPOSED CRITICAL EXPERIMENT DESIGNS

Fast Spectra Experiment Designs

Fast Bare Critical Experiment

The U(19.5%)-10Mo fuel form is designed for use in a thermalized spectrum, complicating attempts to use the fuel in a fast neutron spectrum critical experiment. The initial design for the fast spectra critical experiment sought to use solely the U(19.5%)-10Mo fuel foils. However, due to the low enrichment, a fuel mass of nearly 920 kg was required to achieve criticality even when reflected by graphite. A pragmatic approach was taken, and only the 195 U-Moly foils from the thermal critical experiment were assumed to be available for the fast spectrum experiment.

To overcome the relatively low enrichment of the U-Moly alloy foils, two layers of HEU were added to the system, equal in length and width to the central layer of U-Moly. Essentially, fast spectrum fuel is added to drive the critical reaction. To ensure the fastest possible spectrum, no reflector was added. Therefore the design consists of layers of U-Moly foils sandwiched between two layers of HEU. A diagram of this design is shown below in figure 34.

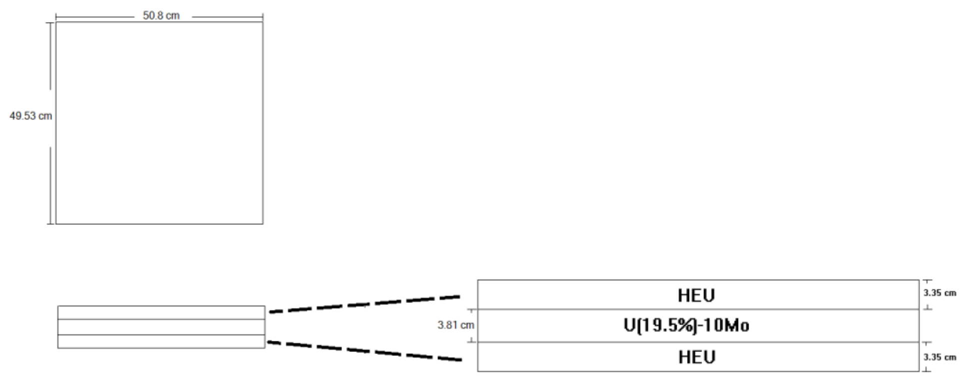

Figure 34) Fast Bare Critical Experiment MCNP Model

The above experimental design results in the fastest possible spectrum in the central U-Moly foil region, however it also requires approximately 319.5 kg of HEU. Figure 35 below compares the spectra, normalized by peak channel, of two fast critical experiments. The proposed bare fast critical experiment, shown in green, has little to no appreciable neutron population in the thermal to resonance energy regimes. The resulting spectrum is close to that of the bare ORNL FBR critical experiments.

An experimental plan and MCNP input listing for the Fast Bare Critical Experiment design can be found in appendices A and B respectively.

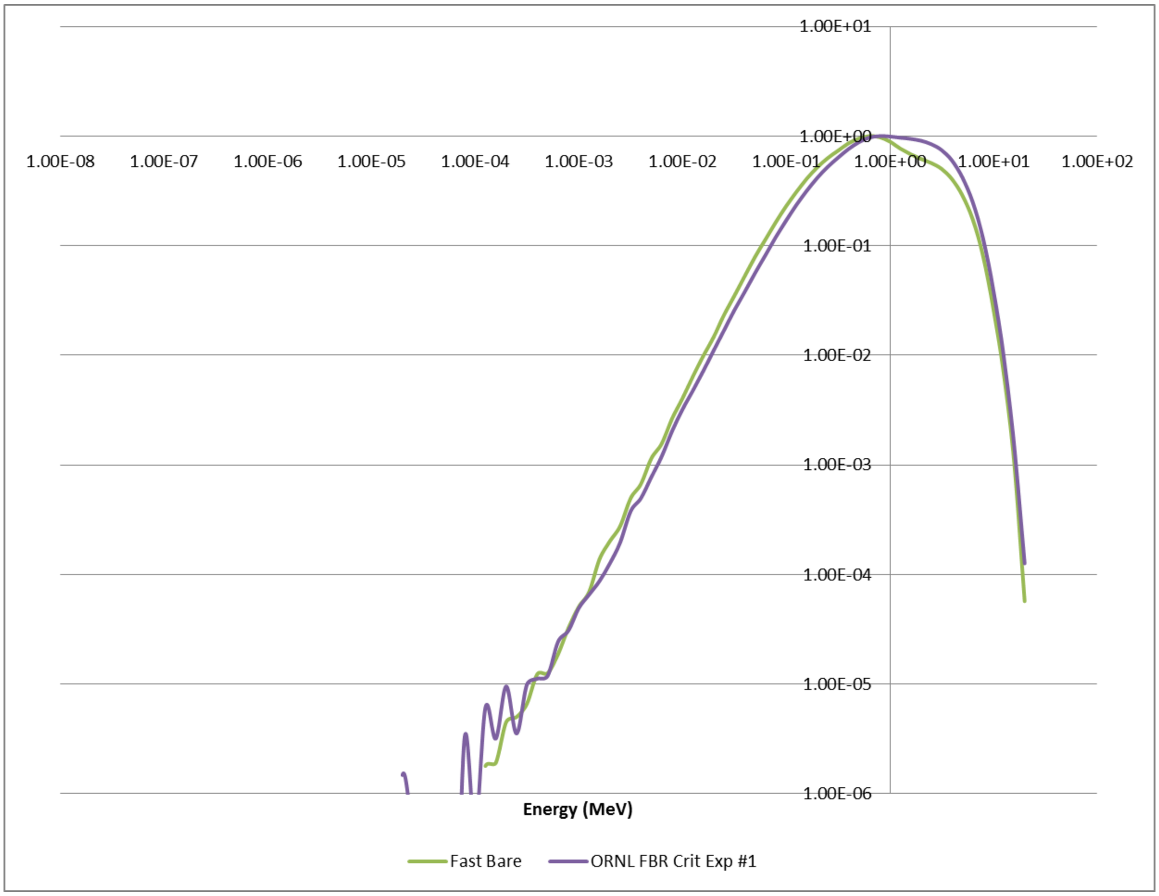

Figure 35) Fast Bare Critical Experiment Spectra

Fast Reflected Critical Experiment

In the event that the quantity of HEU required for the Fast Bare Critical Experiment would be prohibitive, a second critical experiment was designed. The second fast critical experiment design sacrifices some spectrum hardness in order to reduce the required HEU for criticality. A graphite reflector is utilized, as shown below in figure 36. For this configuration, approximately 49.6 kg of HEU is required for criticality.

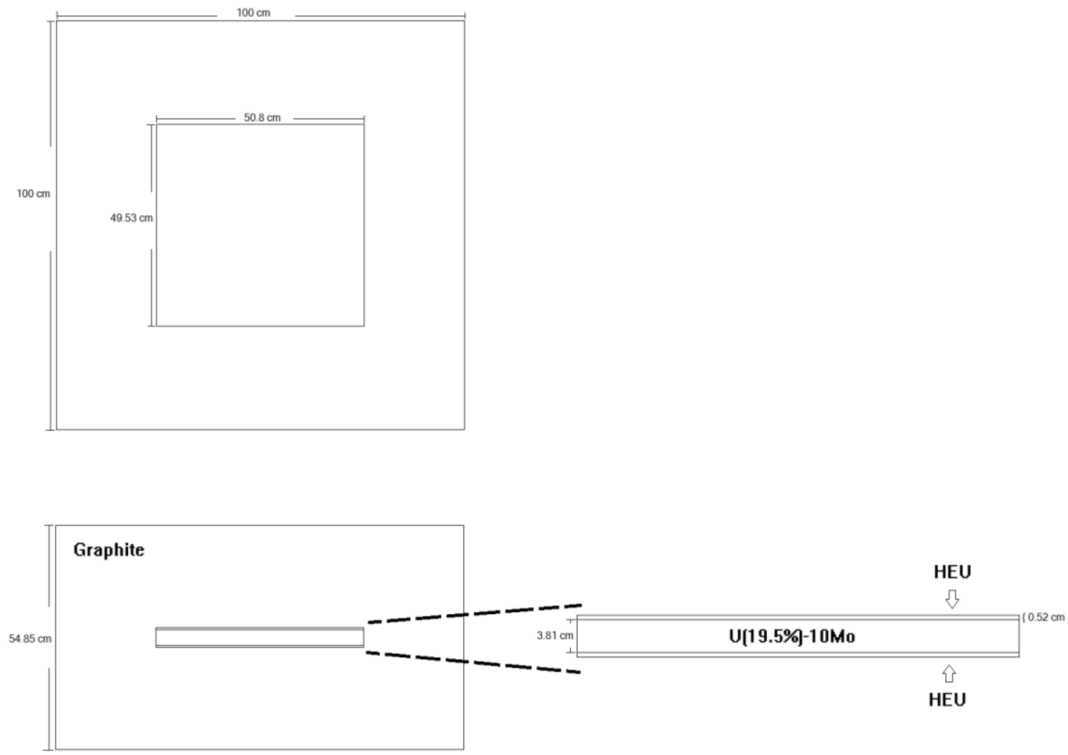

Figure 36) Fast Reflected Critical Experiment MCNP Model

Figure 37 below compares the spectra, normalized by peak channel, of two fast critical experiments. The proposed reflected fast critical experiment, shown in red, has substantially increased neutron population in the resonance and thermal energy regions. The resulting spectrum is approaching that of the reflected ORNL FBR Critical Experiment #4.

An experimental plan and MCNP input listing for the Fast Reflected Critical Experiment design can be found in appendices A and B respectively.

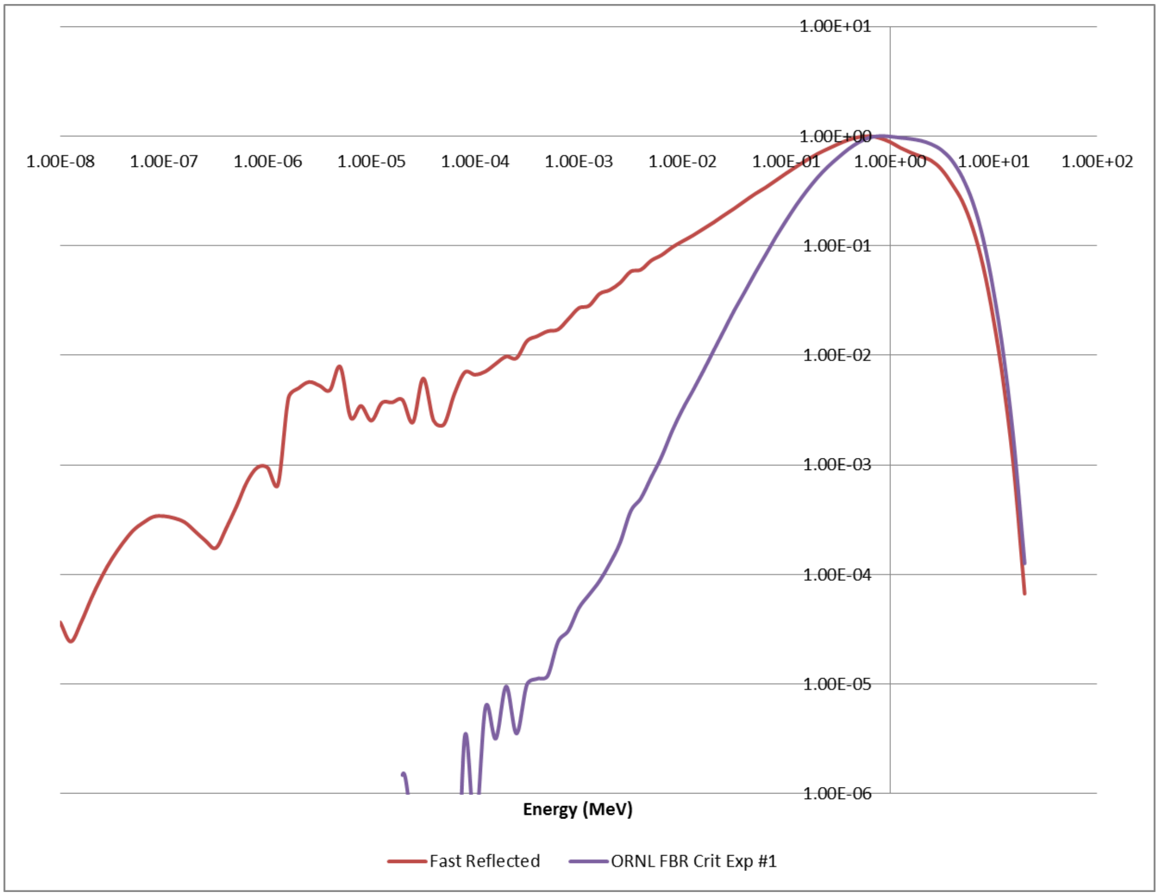

Figure 37) Fast Reflected Critical Experiment Spectra

SCALE's TSUNAMI module was used to calculate sensitivity of system multiplication factor to changes in molybdenum isotope cross-section for all of the proposed critical experiments. Figures 38 through 44 below give the sensitivity per unit lethargy for each of the natural molybdenum isotopes for both fast spectrum critical experiment designs as well as the ORNL FBR Critical Experiment #1.

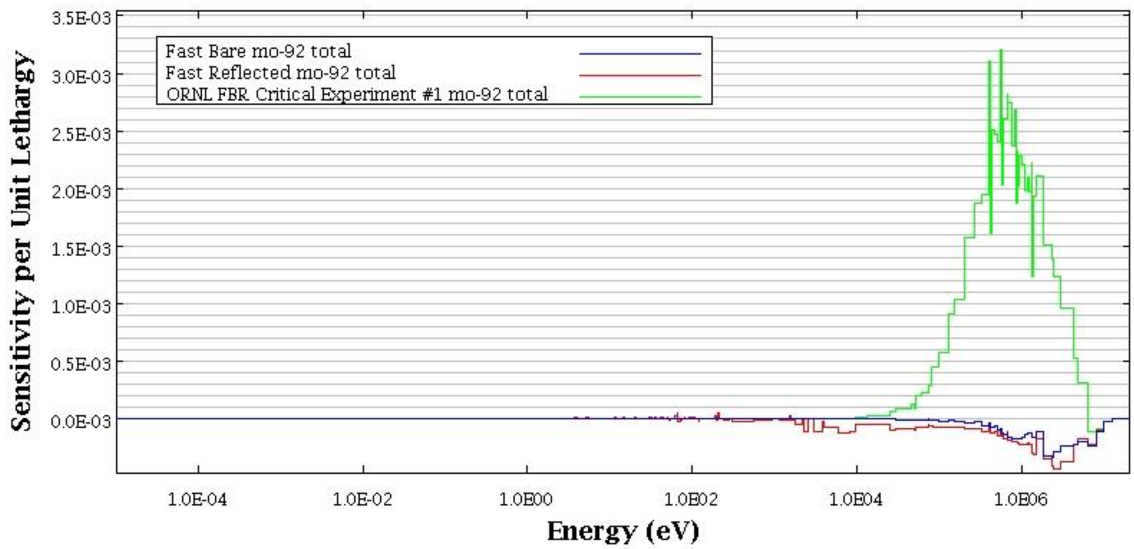

Figure 38) ^{92}Mo Sensitivity for Fast Spectra Critical Experiment Designs

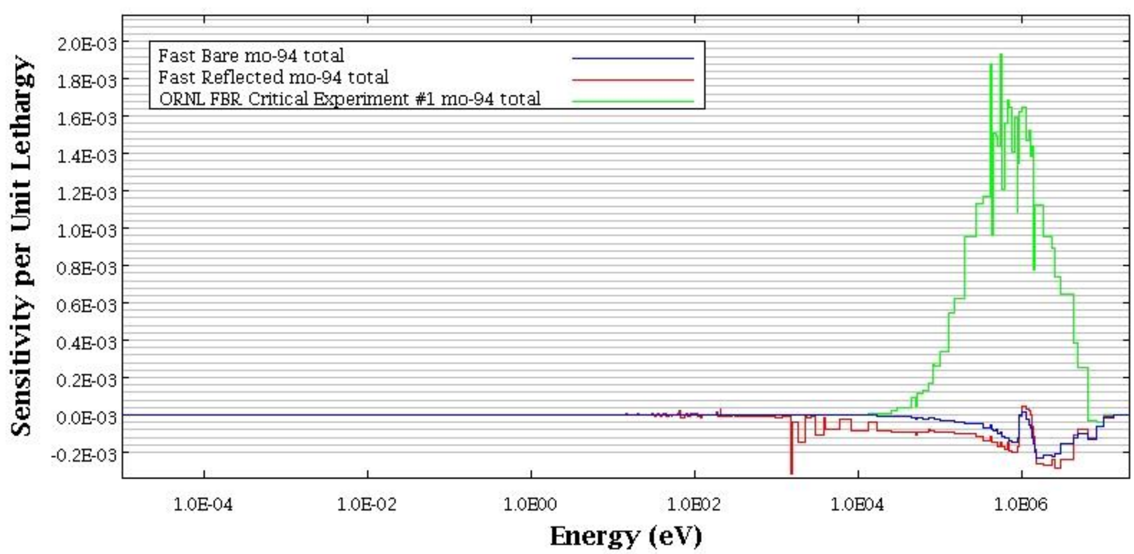

Figure 39) ^{94}Mo Sensitivity for Fast Spectra Critical Experiment Designs

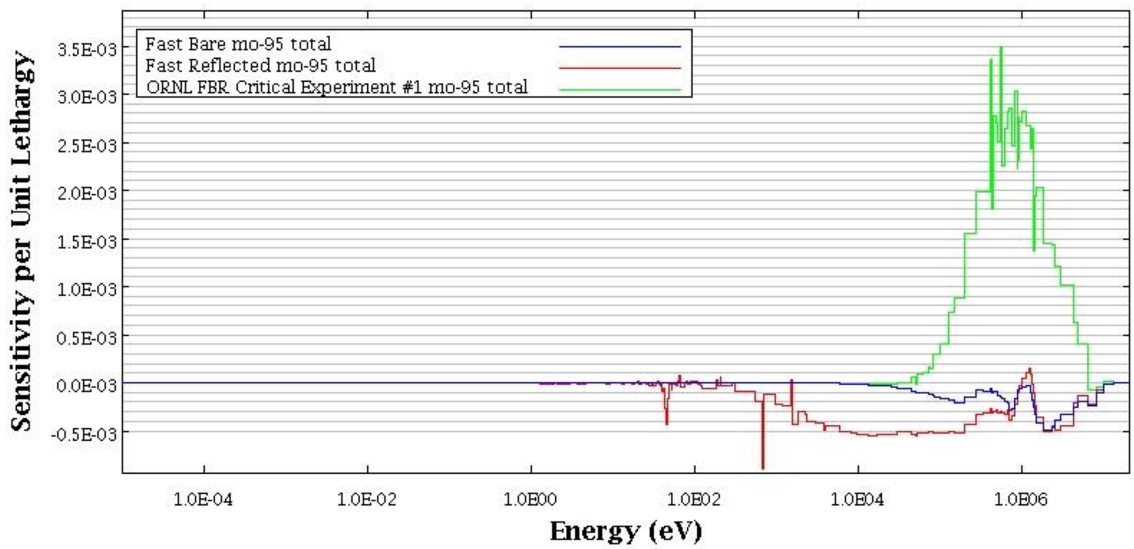

Figure 40) ^{95}Mo Sensitivity for Fast Spectra Critical Experiment Designs

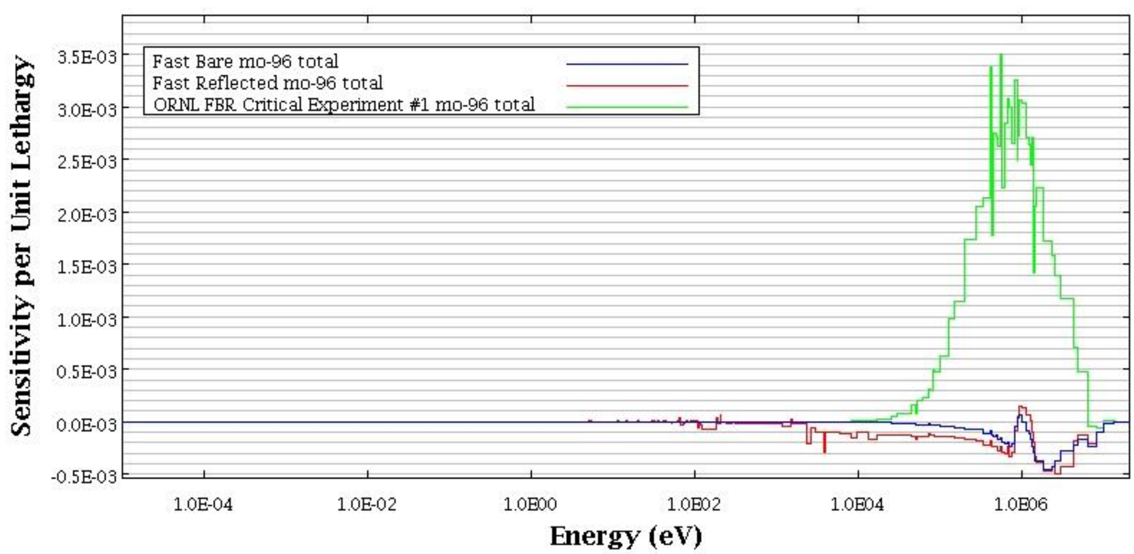

Figure 41) ^{96}Mo Sensitivity for Fast Spectra Critical Experiment Designs

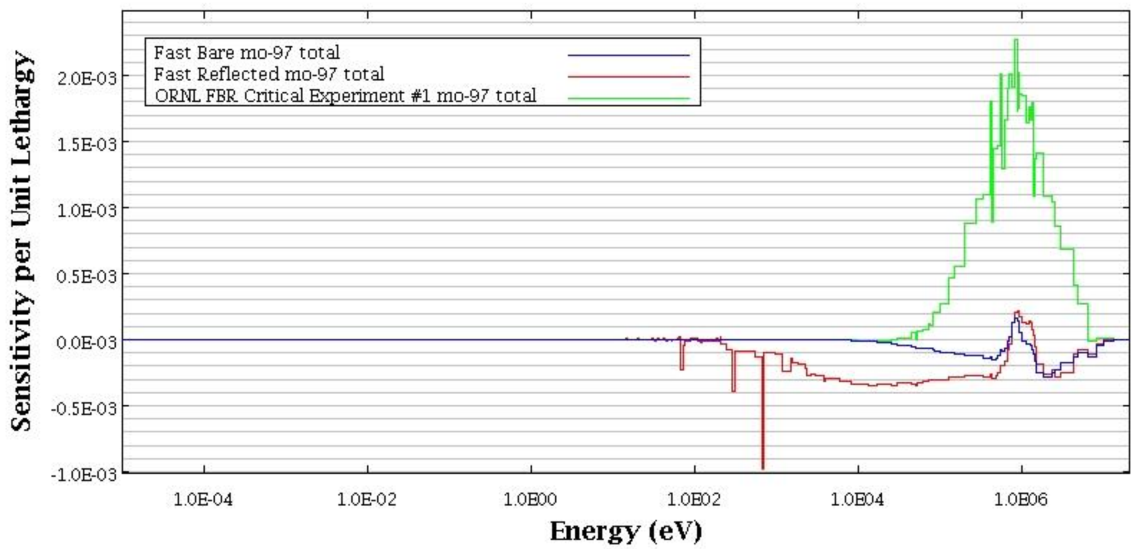

Figure 42) ^{97}Mo Sensitivity for Fast Spectra Critical Experiment Designs

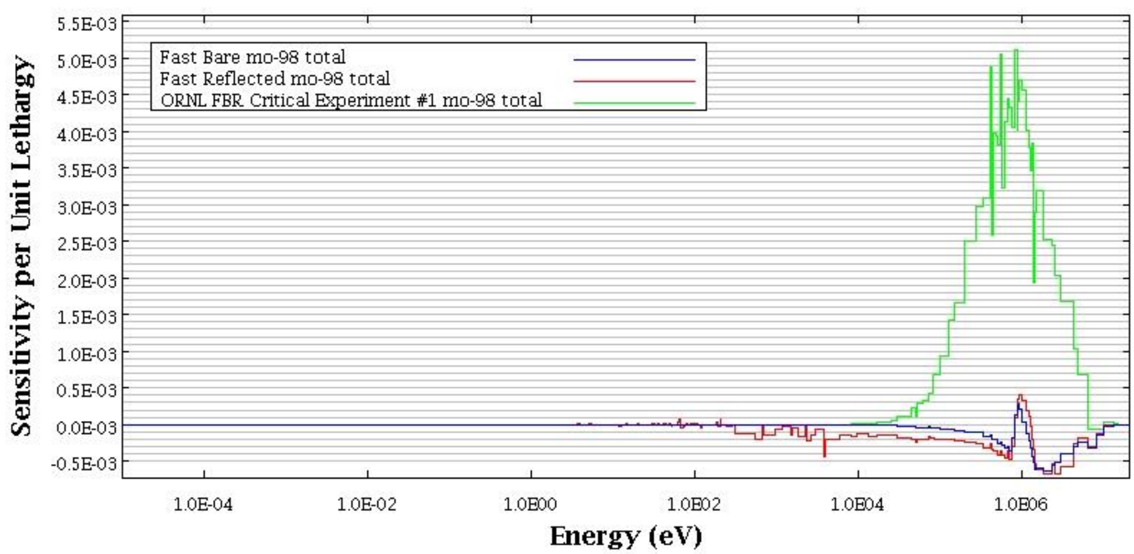

Figure 43) ^{98}Mo Sensitivity for Fast Spectra Critical Experiment Designs

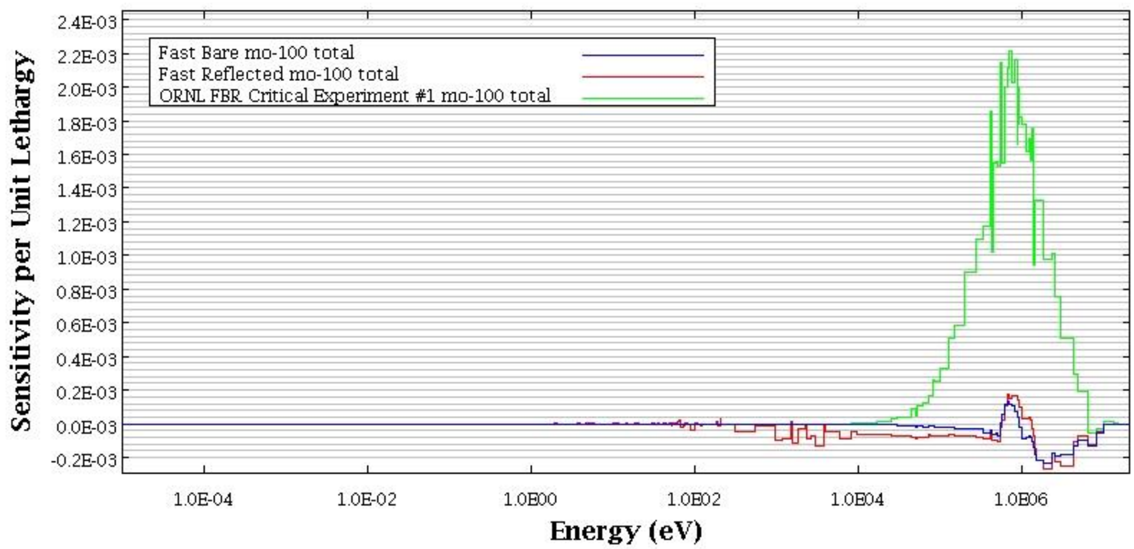

Figure 44) ^{100}Mo Sensitivity for Fast Spectra Critical Experiment Designs

A clear pattern is seen in the above figures. Sensitivity for the three critical experiments is concentrated in the high energy region, though the Fast Reflected experiment design does show some sensitivity in the resonance energy region. However, the ORNL FBR critical experiment exhibits significantly more sensitivity to the molybdenum isotopes than the proposed U-Moly critical experiment designs. This derives from the issue described previously in designing a fast spectrum critical system using low density fuel intended for a thermal spectrum. Fast spectrum fuel must be included as a driver to achieve criticality while avoiding neutron moderation. Therefore the overall sensitivity of k_{eff} of the system to the molybdenum fuel is reduced: the HEU drives the reaction so the system sensitivity is concentrated in a region lacking molybdenum. However, given the low ^{235}U density of the U-Moly fuel as compared to the HEU, the two proposed critical experiment designs offer the most fast spectrum molybdenum sensitivity achievable with the U-Moly fuel.

Figures 45 and 46 below show the sensitivity of k_{eff} to the group-wise total cross-sections for the molybdenum isotopes and for ^{235}U and ^{238}U respectively for the fast spectra critical experiment designs.

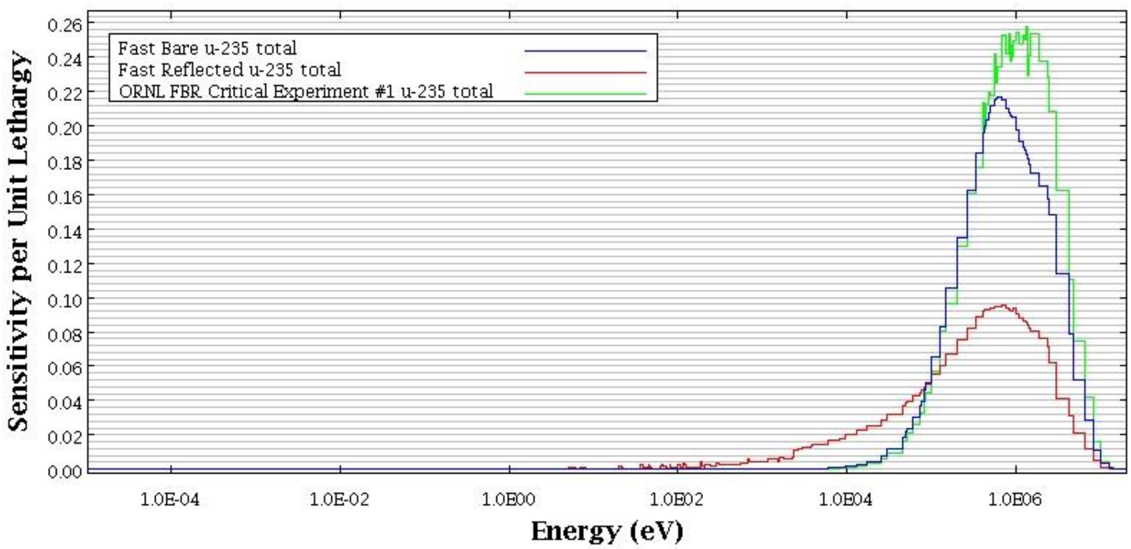

Figure 45) ^{235}U Sensitivity for Fast Spectra Critical Experiment Designs

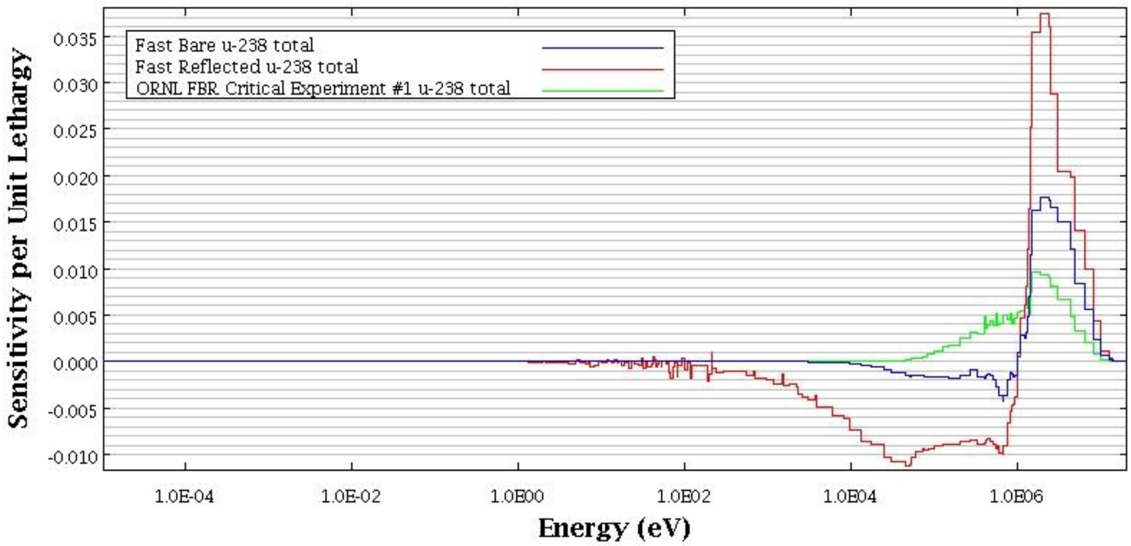

Figure 46) ^{238}U Sensitivity for Fast Spectra Critical Experiment Designs

As compared to the unreflected case, figures 40 and 42 shows increased sensitivity in the resonance region, particularly large resonance responses are seen for ^{95}Mo and ^{97}Mo. In addition to high sensitivity to ^{235}U, the proposed system would also be highly sensitive to cross-section changes in the graphite of the reflector.

Table 15) Differences in Modeled Fast Critical Experiment k_{eff} Due to Cross Section Library

	Fast Bare Exp.		**Fast Reflected Exp.**		**ORNL FBR #1**	
	k_{eff}		k_{eff}		k_{eff}	
ENDF	0.99960		0.99927		0.99609	
JEFF	0.99984		0.99873		0.99660	
JENDL	0.99961		0.99913		0.99720	
	del K/K	*pcm*	*del K/K*	*pcm*	*del K/K*	*pcm*
ENDF vs JEFF	0.00024	24.00384	-0.00054	-54.0687	0.000512	51.17399
ENDF vs JENDL	1.00E-05	1.00039	-0.00014	-14.0122	0.001113	111.3117
JENDL vs JEFF	-0.00023	-23.009	0.00040	40.03483	0.000602	60.16847

A numerical quantification of the integral system response to molybdenum cross-section uncertainty is given above in table 15, which shows the difference in multiplication factor of the experimental system modeled using molybdenum cross-section data from three different libraries: ENDF/B VII.1, JEFF3.3, and JENDL3.0. These results are somewhat surprising. As could be expected due to its higher molybdenum sensitivity, the ORNL FBR critical experiment exhibits the greatest deviation in multiplication factor across cross-section libraries. However, the proposed fast U-Moly critical experiments still exhibit significant differences in k_{eff}, despite significantly less sensitivity to the molybdenum isotopes. In particular, the Fast Reflected design exhibits over twice the deviation in k_{eff} as compared to the Fast Bare design, likely due to the increased neutron flux in the resonance region owing to moderation from the graphite reflector.

Thermal Spectra Experiment Designs

The U-Moly fuel foils are designed for a thermal spectrum. However, to date, there are no thermal spectrum critical experiments containing uranium-molybdenum alloy fuels. The following details two proposed thermal spectrum critical experiments featuring the U-Moly fuel foils: one comprised of the uranium molybdenum foils interleaved with moderator and surrounded by a reflector, referred to as the Thermal Standard Molybdenum Critical Experiment, and one composed similarly to the Thermal Standard experiment, but with additional molybdenum metal only layers between the fuel foils and moderator. The purpose of this design is to achieve the maximum sensitivity possible to the molybdenum cross-section in a thermal neutron spectrum, and is referred to as the Thermal Maximum Molybdenum Critical Experiment.

Thermal Standard Molybdenum Critical Experiment

For both of the thermal spectrum experiment designs, plexiglass or Lucite was chosen as the moderator, as it has a high hydrogen density while also being easy to handle, and can be inexpensively procured in the necessary geometries for the experimental set up.

In order to obtain a first order estimate of the amount of fuel material required a regular parallelepiped, 20" x 19.5" x 19.685", made up of a homogeneous mix of U(19.5%)-10Moly fuel and plexiglass was modeled using MCNPX. The dimensions of the parallelepiped were chosen as the foils produced by Y-12 are 20" long and 1.5" wide; using 13 foils side-by-side per "sheet" would most closely approximate a right cube, which would have the lowest neutron leakage of the geometries possible with the foils.

When modeled as described above, the minimum critical mass of fuel was just less than 17 kilograms. Including a 25 cm thick graphite reflector on all sides reduced the minimum critical mass to just over 12 kilograms. [30] Below in figure 47 is a plot of MCNPX calculated spectra for the bare and reflected cases, along with the spectra for the most thermalized ORNL FBR design critical experiment, all normalized by peak channel value. The proposed experimental design would offer a thermal-to-fast flux ratio orders of magnitude higher thermalized than any of the experiments currently in existence.

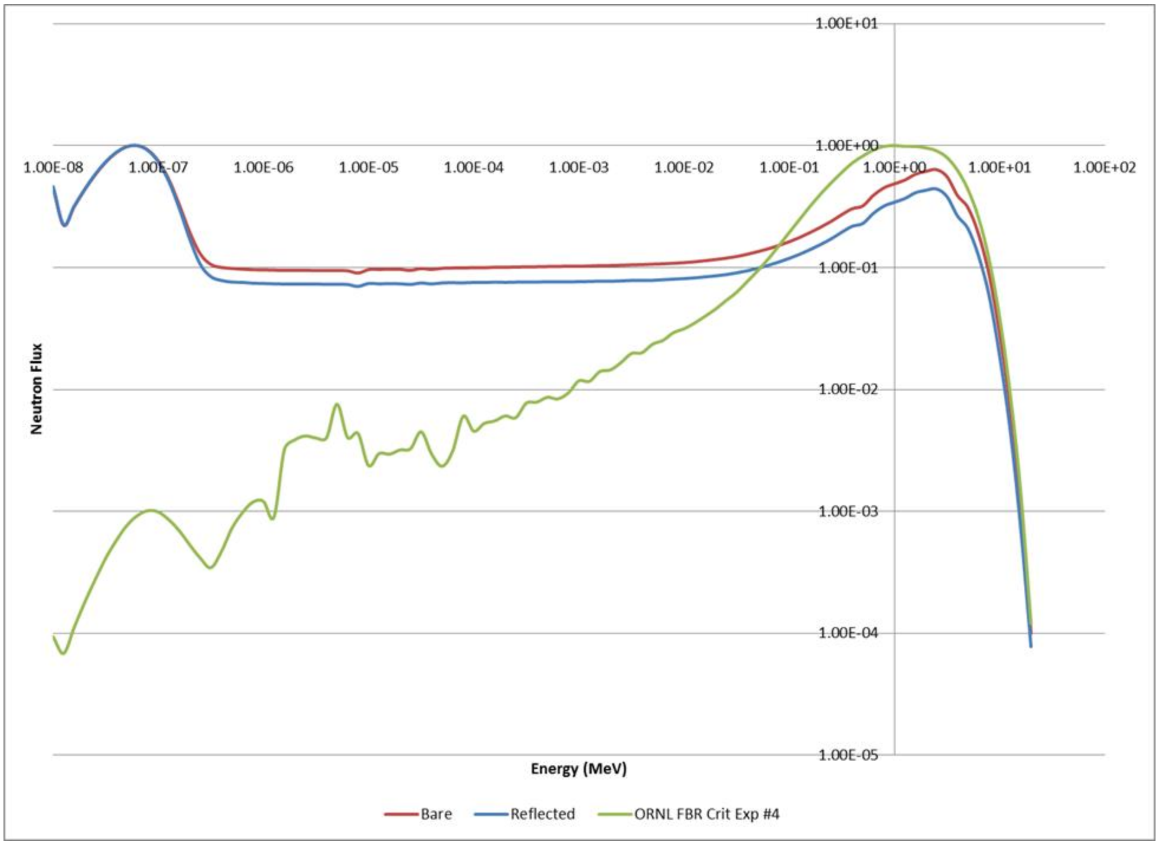

Figure 47) Calculated Spectra of Homogenized U-Moly Fuel and Lucite Moderator

Given that the scoping calculations were promising, to support a precise design a more realistic computational model was needed, specifically one with heterogeneous layers of fuel and moderator to account for the effects of ^{238}U. The MCNP calculations were repeated with such a heterogeneous system: layers of fuel interlaced with layers of moderator. Example input decks are presented in Appendix C. The minimum critical system in this configuration had 15 fuel layers of 13 foils each, for a total of 195 required fuel foils, with a ~25 cm thick graphite reflector. This loading of fuel foils will contain 14.67 kg of uranium metal, and 2.86 kg of ^{235}U. As the number of fuel layers will not be easily alterable, the thickness of the graphite reflector could serve as a criticality control for the experiment, along with the separation distance between the subcritical systems.

Shown below in figure 48 is the final thermal experiment model. The figure is not necessarily drawn to scale, but rather to clearly show geometry details.

This model is simplified, not taking into account geometric variation or material impurities in fuel foils or moderator as well as neglecting the effects of the room surrounding the critical experiment as well as the Comet experimental machine itself. These simplifications would be resolved if the design process continued. In particular, the precise composition of the actual physical experimental elements (fuel foils, Lucite and graphite blocks) would need to be finalized. But for a reflected experiment, high-fidelity modeling of room and experimental apparatus was found in other similar critical experiment models to have minimal effects, generally within calculation uncertainty. [31][32][33]

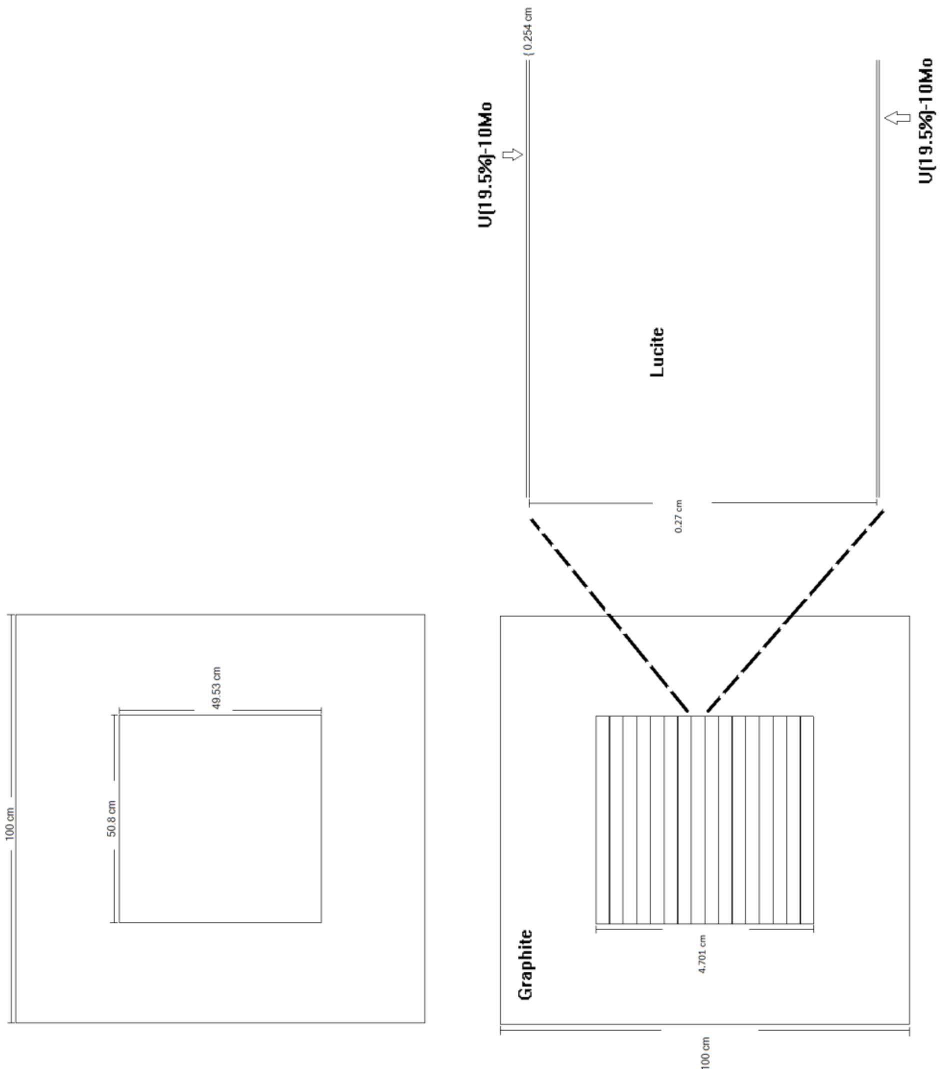

Figure 48) Thermal Standard Molybdenum Critical Experiment MCNP Model

Below, in figure 49, is a plot of MCNPX calculated spectra of the proposed thermal standard molybdenum critical experiment. This spectrum is not as thermalized as the hypothetical homogenized spectra shown previously; however it is significantly more thermalized than any existing uranium-molybdenum alloy fueled critical experiment.

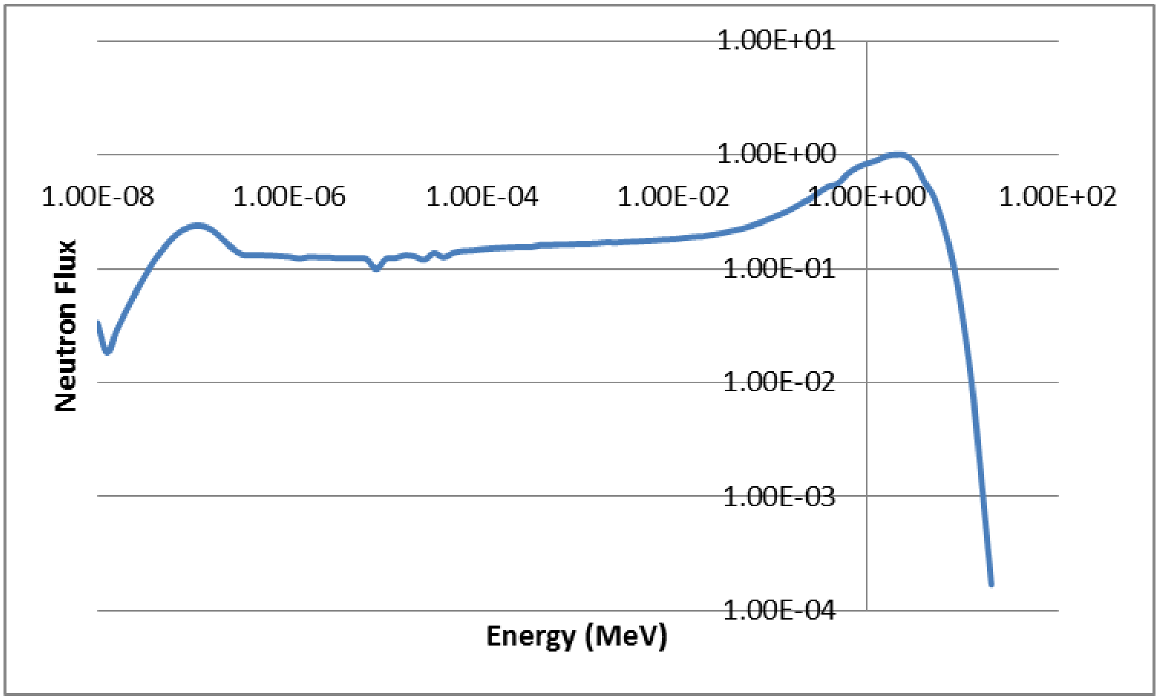

Figure 49) Thermal Standard Molybdenum Critical Experiment Spectra

Thermal Maximum Molybdenum Critical Experiment

In order to maximize the system sensitivity with respect to molybdenum, an additional critical experiment was designed, based on the initial thermal critical experiment design. Additional layers of pure molybdenum foil were added for each fuel foil, and the thickness of the molybdenum only foils and the Lucite moderating layers were iterated upon until a critical system with the maximum amount of molybdenum metal was achieved. Additionally the thickness of the graphite reflector was doubled. This design includes approximately 7 times the molybdenum as the initial thermal critical experiment design, while maintaining a highly thermalized neutron spectrum. Figures 50 and 51 below give the model design and calculated neutron spectrum as compared to the standard thermal critical experiment design respectively.

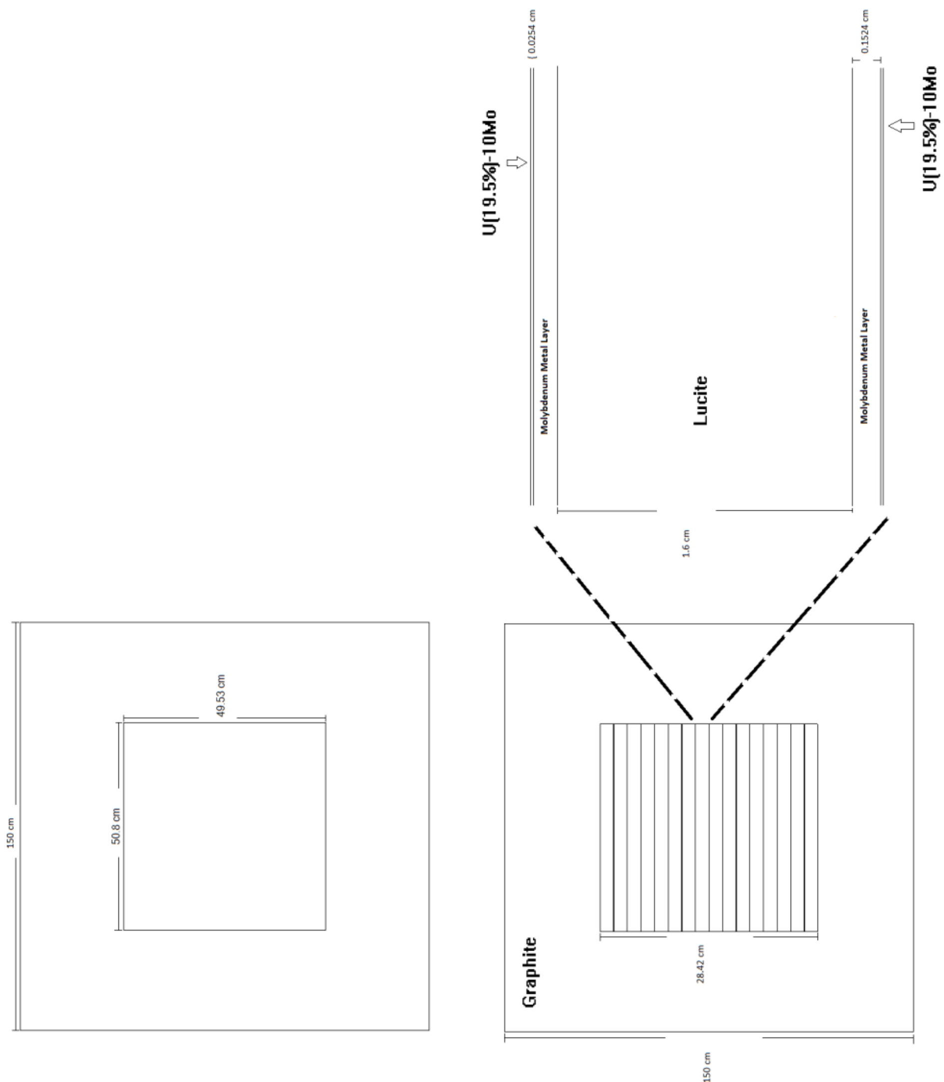

Figure 50) Thermal Maximum Molybdenum Critical Experiment MCNP Model

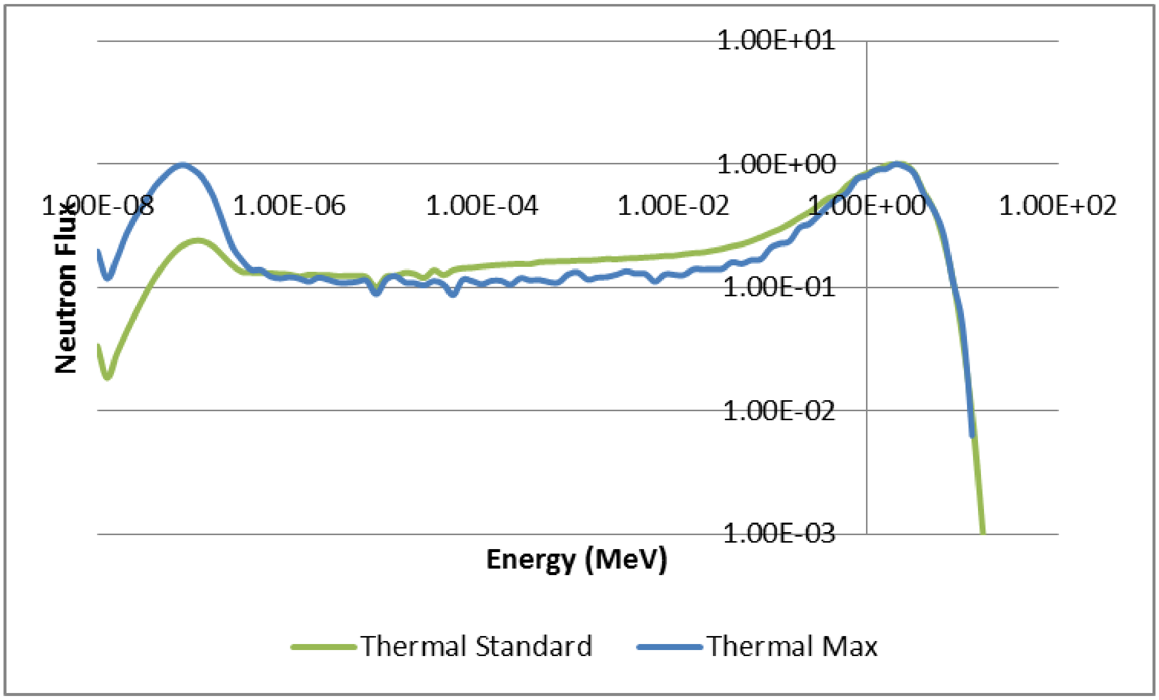

Figure 51) Spectra for Standard and Maximum Molybdenum Thermal Critical Experiments

As expected, dips in the neutron spectra due to resonance effects from molybdenum isotopes are more pronounced in the design with maximum molybdenum content. Additionally, the spectrum is more thermalized for the Maximum Molybdenum design as compared to the Standard Molybdenum design, which is to be expected as additional hydrogenous moderating material was required to achieve criticality. The spectrum of the Maximum Molybdenum Thermal Critical Experiment is orders of magnitude more thermalized than existing critical experiments utilizing U-Mo fuel.

As with the fast spectrum designs, the thermal critical experiment systems were modeled in SCALE to take advantage of its TSUNAMI sensitivity and uncertainty package. Figures 52 through 58 below give the sensitivity per unit lethargy for each of the natural molybdenum isotopes for both thermal spectrum critical experiment designs as well as the most thermalized ORNL FBR critical experiment, ORNL FBR Critical Experiment #4.

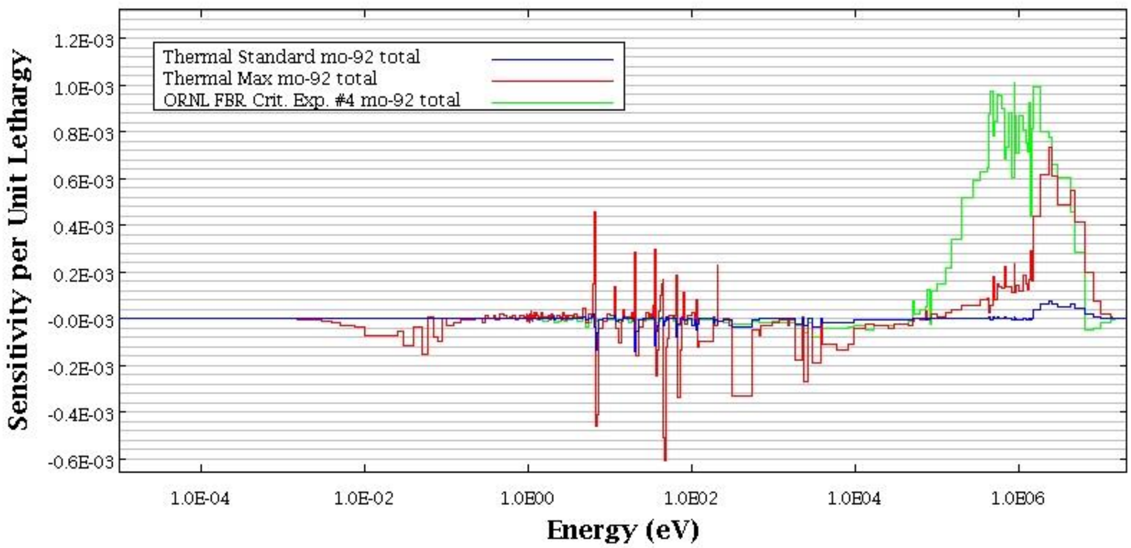

Figure 52) ^{92}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

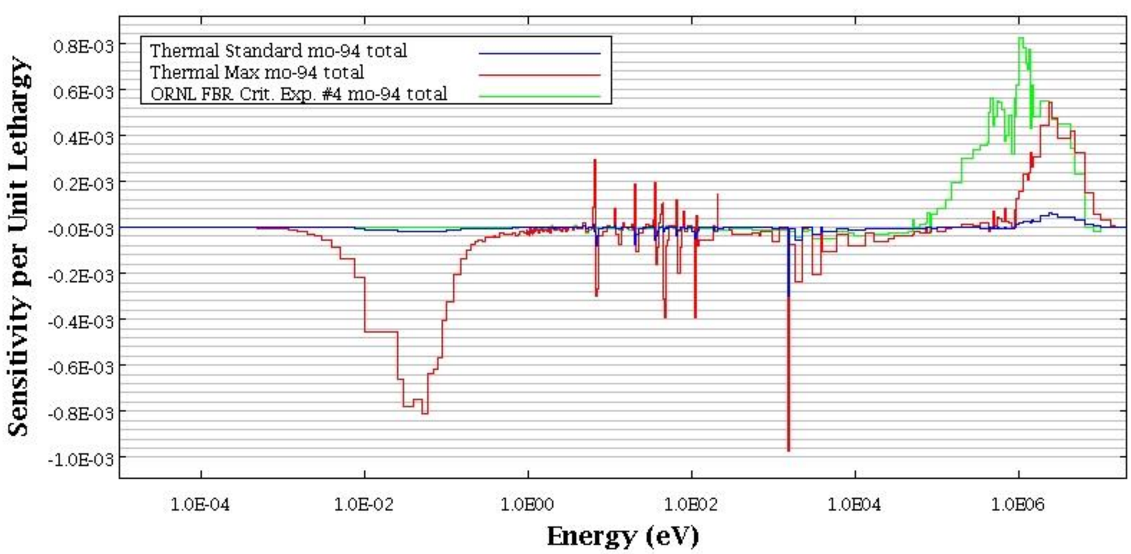

Figure 53) ^{94}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

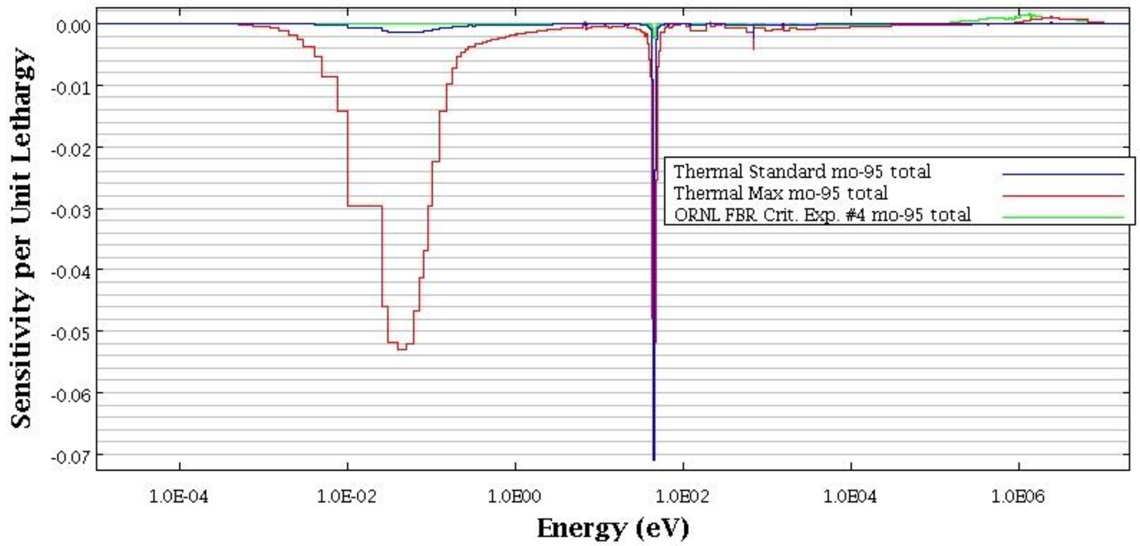

Figure 54) ^{95}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

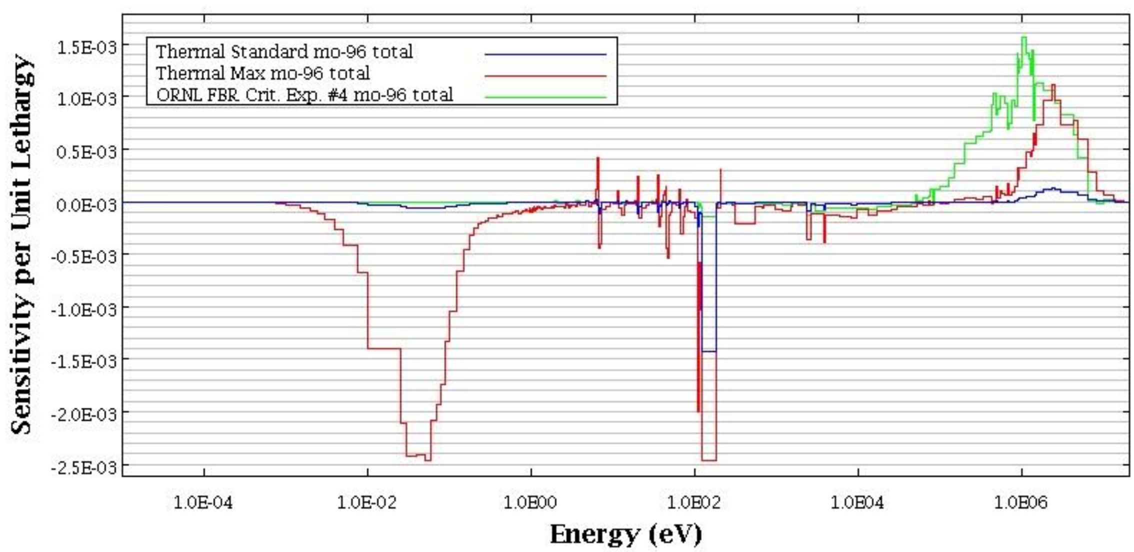

Figure 55) ^{96}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

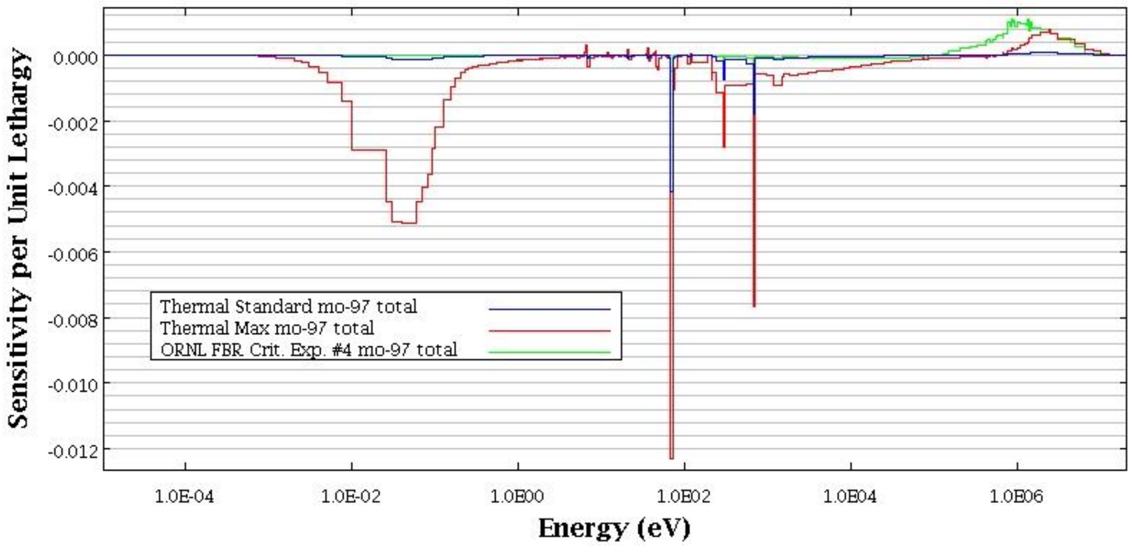

Figure 56) ^{97}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

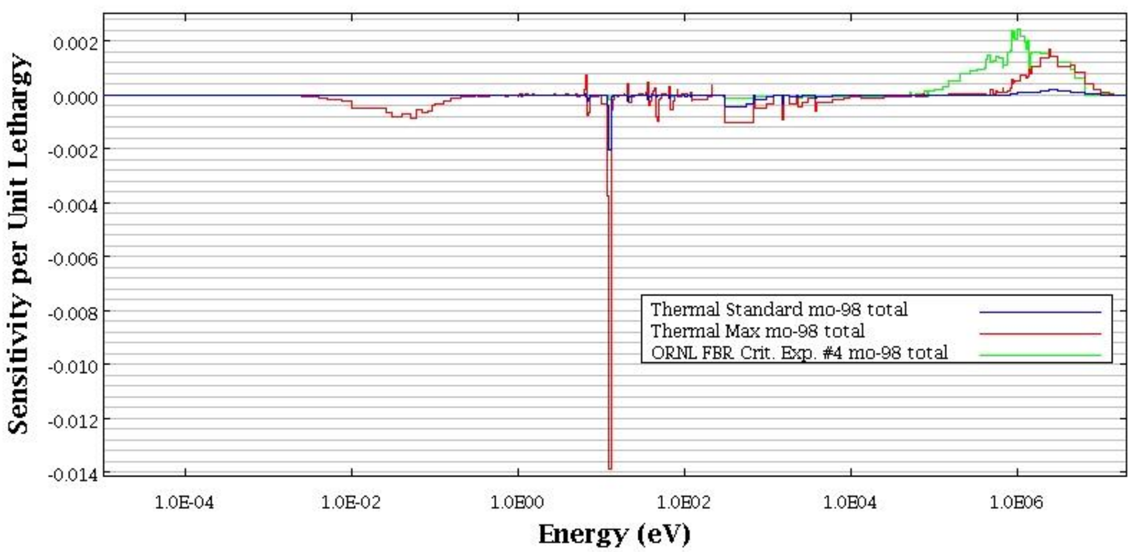

Figure 57) ^{98}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

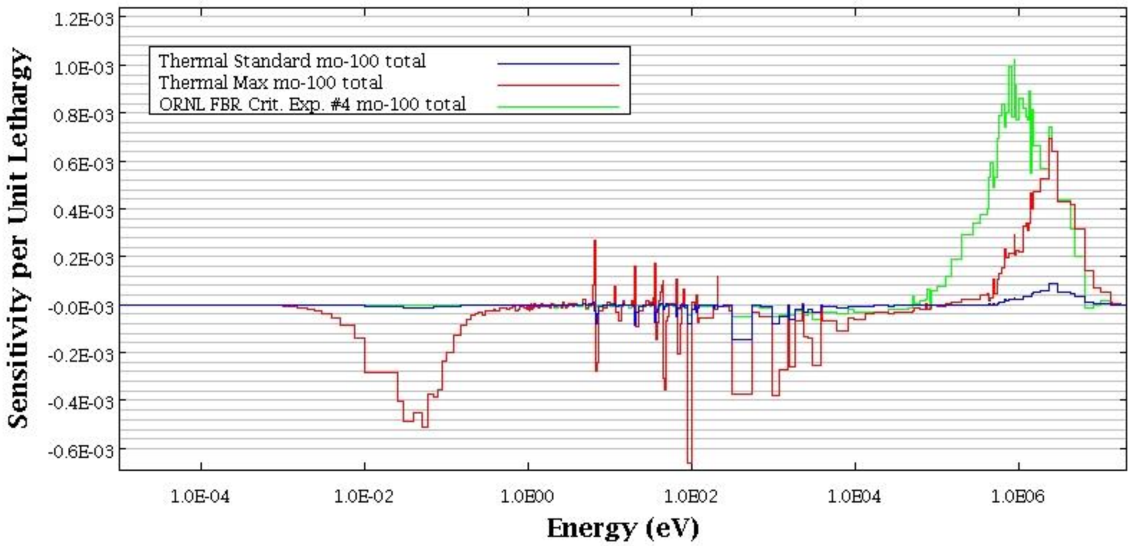

Figure 58) ^{100}Mo Sensitivity for Thermal Spectra Critical Experiment Designs

Similar to the fast spectra designs, the existing ORNL FBR critical experiment shows greater sensitivity to molybdenum in the fast energy region. This is to be expected, as the spectrum of the ORNL experiment is still orders of magnitude faster than either of the proposed thermal designs. The Thermal Standard Molybdenum Critical Experiment design overall demonstrates low sensitivity to the molybdenum isotopes. This is primarily due to the overriding sensitivity effects of hydrogen in the heavily moderated system, as seen below in figure 59. Additionally, there are simply few molybdenum atoms in the system as compared to the two other thermal critical experiments.

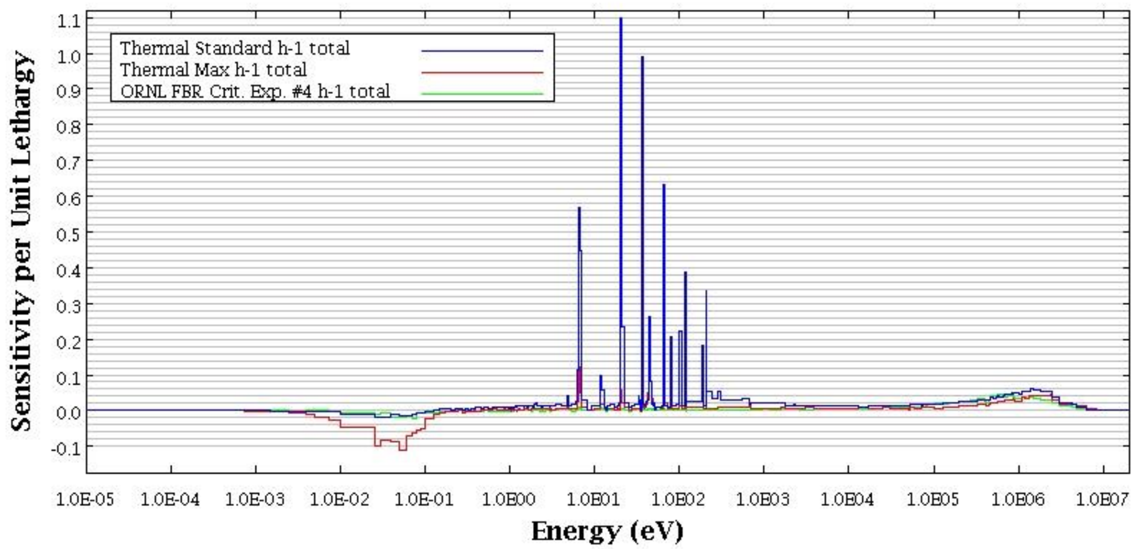

Figure 59) ^{1}H Sensitivity for Thermal Spectra Critical Experiment Designs

However, the Thermal Maximum Molybdenum Critical Experiment demonstrates high levels of sensitivity to the molybdenum isotopes, especially throughout the resonance region. The influence of large individual resonances can be clearly seen for most of the molybdenum isotopes. Table 16 below gives integral sensitivity values for the Standard and Maximum Molybdenum critical experiment designs. Sensitivity to molybdenum increased by nearly two orders of magnitude for some isotopes in the Maximum Molybdenum critical experiment design.

Table 16) Integral Molybdenum Isotope Sensitivity for Standard and Maximum Molybdenum Critical Experiment Designs

Isotope	Standard Molybdenum Design	Maximum Molybdenum Design
^{92}Mo	2.745E-05	-7.029E-05
^{94}Mo	-6.435E-05	-1.695E-03
^{95}Mo	-8.040E-03	-1.317E-01
^{96}Mo	-7.686E-04	-6.348E-03
^{97}Mo	-1.108E-03	-1.546E-02
^{98}Mo	-5.632E-04	-3.272E-03
^{100}Mo	-1.190E-04	-1.127E-03

A numerical quantification of the proposed critical experiment system response to molybdenum cross-section uncertainty is given below in table 17, which shows the difference in multiplication factor of the experimental system modeled using molybdenum cross-section data from three different libraries: ENDF/B VII.1, JEFF3.3, and JENDL3.0.

Table 17) Differences in Modeled Thermal Critical Experiment K_{eff} Due to Cross Section Library

	Thermal Standard		Thermal Max		ORNL FBR #4	
	K_{eff}		K_{eff}		K_{eff}	
ENDF	0.99801		1.00026		1.00999	
JEFF	0.99795		1.00115		1.00987	
JENDL	0.99830		0.99984		1.01076	
	del K/K	*pcm*	*del K/K*	*pcm*	*del K/K*	*pcm*
ENDF vs JEFF	-0.00006	-6.41316	0.00089	88.89777	-0.00012	-11.88270
ENDF vs JENDL	0.00029	29.04933	-0.00042	-42.00672	0.00076	76.18030
JENDL vs JEFF	0.00035	35.46021	-0.00131	-131.02096	0.00088	88.05255

Despite its low sensitivity to the molybdenum isotopes, the Thermal Standard Molybdenum critical experiment design exhibits deviation in multiplication factor of roughly the same order of magnitude as the fast spectrum critical experiment designs. However, the Thermal Maximum Molybdenum critical experiment design exhibits the largest deviation in multiplication factor of any critical experiment design, either existing or proposed.

CONCLUDING REMARKS

A series of critical experiments is proposed to address deficiencies in the current library of evaluated criticality benchmarks with regards to sensitivity to molybdenum isotopes, especially in thermal neutron spectra, as constituent fuel material, as in the new U(19.5%)-10Moly alloy foil fuel form. Four experiments are proposed:

1) A fast spectrum system comprised of U-Moly foils and HEU.
2) An intermediate-to-fast spectrum system comprised of U-Moly foils and HEU, reflected by graphite.
3) A thermalized spectrum experiment interleaving U-Moly foils with Lucite moderator layers, all reflected by graphite.
4) A highly thermalized spectrum experiment interleaving U-Moly foils with Lucite moderator layers and layers of molybdenum metal, all reflected by graphite.

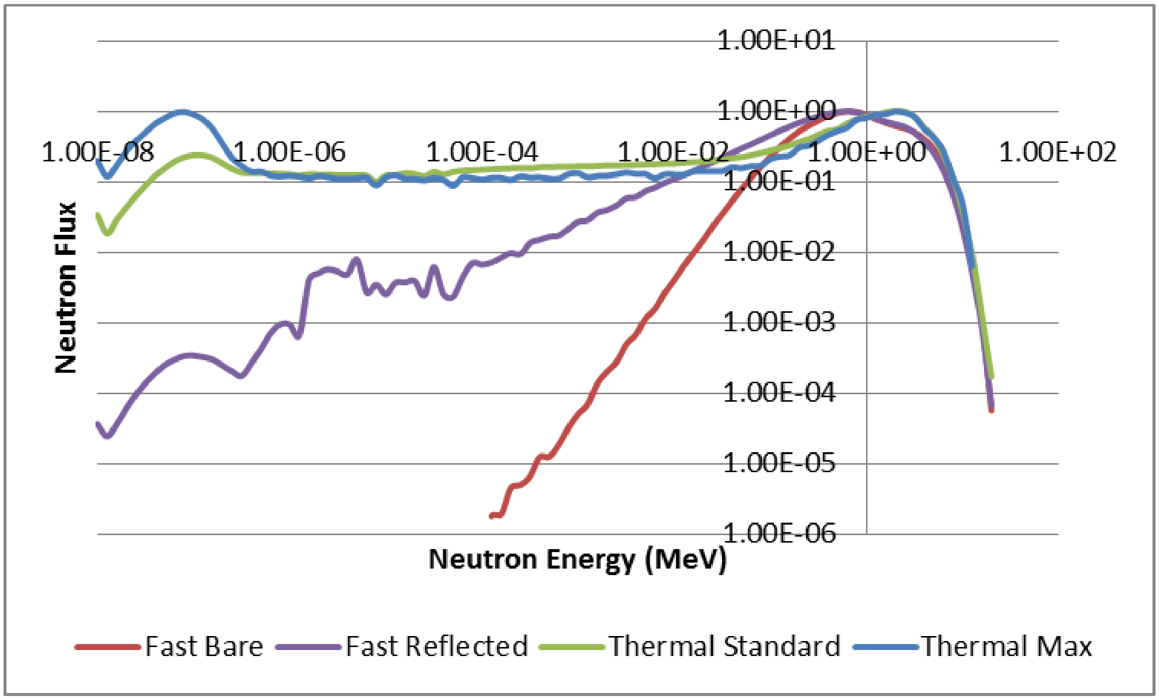

Figure 60) Calculated Spectra for Proposed Critical Experiment Designs

Figure 60 above compares the MCNPX calculated spectra for the proposed critical experiments, normalized by peak channel. The proposed thermal spectrum systems exhibits sensitivity to molybdenum cross-section changes at low neutron energies which no experiment currently in the ICSBEP includes. Additionally, comparison between the four critical experiments may help determine energy regions of high molybdenum cross-section uncertainty. Such improved uncertainty data should aid modeling efforts of nuclear systems utilizing uranium-molybdenum alloy fuels in the future such as the Advanced Test Reactor at Idaho National Laboratory and the High Flux Isotope Reactor at Oak Ridge National Laboratory.

Chapter 4: Covariance Data Generation

To go from raw experimental data, with its inherent uncertainty, to evaluated nuclear data usable in system modeling requires many steps, through which the data uncertainties must be propagated. This associated uncertainty must be retained as covariance data within the ENDF files. The current ENDF data format includes two means of recording cross section covariance data: parameter-wise covariance data in file 32 and group-wise covariance data in file 33 [2][3]. Both of these file formats have advantages, and both must often be used in tandem to fully describe an isotope's cross-section uncertainty data.

In this section, a method is demonstrated for generating complete covariance data sets, including both files 32 and file 33 formatted data, for the natural isotopes of molybdenum. The retroactive covariance method of the SAMMY R-matrix analysis code is used to generate the resonance parameter-wise uncertainty and correlations found in file 32 from experimental data. A combination of integral measurement uncertainty, a dispersion method, and high energy covariances produced with the Empire-KALMAN code is used to generate the group-wise file 33 covariance data.

File 32 Format Covariance Data

RPI Experimental Data

A series of transmission and capture yield experiments were completed at the RPI LINAC facility using a natural molybdenum target. The primary purpose of that work was to generate an improved set of resonance parameters for the molybdenum isotopes.

A majority of current experimental cross-section evaluations, including the RPI natural molybdenum measurements, do not retain their resonance parameter covariance matrix. However, the functionality exists in SAMMY to retroactively generate these missing covariance matrices. The first step in generating covariance data for experimental data is to generate a fit to the experimental data using SAMMY. In general, this process can be lengthy, as an initial "guess" of resonance parameters must be obtained, either through a parameter estimation code such as RSAP, or by using a parameter set from a prior evaluation. Manual adjustment of parameters and addition of parameters for resonances that were not included previously must then be undertaken over the course of many SAMMY runs to generate the final best fit set of resonance parameters. However, this process was significantly shortened for this work, as a set of resonance parameters for the experimental data had already been produced and published in Ref. [34].

The initial goal was therefore to duplicate the SAMMY results of Ref. [34], including effects of experimental resolution and Doppler broadening, self-shielding, and multiple-scattering events. Doing so required knowledge of the experimental conditions, which are detailed in tables 18 and 19.

Table 18) Molybdenum Experimental Details

Experiment	Overlap Filter	Neutron Producing Target	Electron Pulse Width (ns)	Average Beam Current (μA)	Beam Energy (MeV)	Energy Region	Channel Width (μS)	Pulse Repetition Rate	Flight Length Path (m)
Epithermal Transmiss ion 2004	Boron Carbide	Bare Bounce	47	23	52	E < 38 eV 38 eV <E<148eV E>148 eV	0.5 0.125 0.03125	225	25.596
Epithermal Transmission 1995	Boron Carbide	Old Bounce	47	26	50	E<28 eV E>148 eV	0.5 0.03125	250	25.53
Epithermal Capture 1995	Boron Carbide	Old Bounce	100	36	50 - 60	E<28 eV E>148 eV	0.5 0.03125	200	25.567

Table 19) Elemental Metal Molybdenum Samples

Nominal Thickness (mm)	Atom Density (atoms/b)	Uncertainty (atoms/b)	Measurements
0.051	3.088E-04	1E-07	Capture 10 to 600 eV
0.127	7.897E-04	1.6E-06	1995 transmission 10 to 200 ev, capture 10 to 600 eV
0.254	1.642E-03	2E-06	1995 transmission 10 to 200 ev, capture 10 to 600 eV
0.508	3.259E-03	4E-06	Capture 10 to 600 eV
0.635	4.077E-03	4E-06	1995 transmission 10 to 200 ev
1.27	8.160E-03	8E-06	1995 transmission 10 to 200 ev
2.54	1.649E-02	2E-05	1995 transmission 10 to 200 ev, 2004 transmission 10 to 2000 eV
5.08	3.142E-02	3E-05	1995 transmission 10 to 200 ev
6.35	3.958E-02	3E-05	2004 transmission 10 to 2000 eV

Analysis with SAMMY

The initial step to generating resonance wise covariance data was to reproduce the resonance parameter fit to the experimental data as reported by the RPI experimentalists. This was accomplished for the 2004 0-2000 eV transmission data and the 1995 0-600 eV capture data, shown below in figures 61 and 62 respectively.

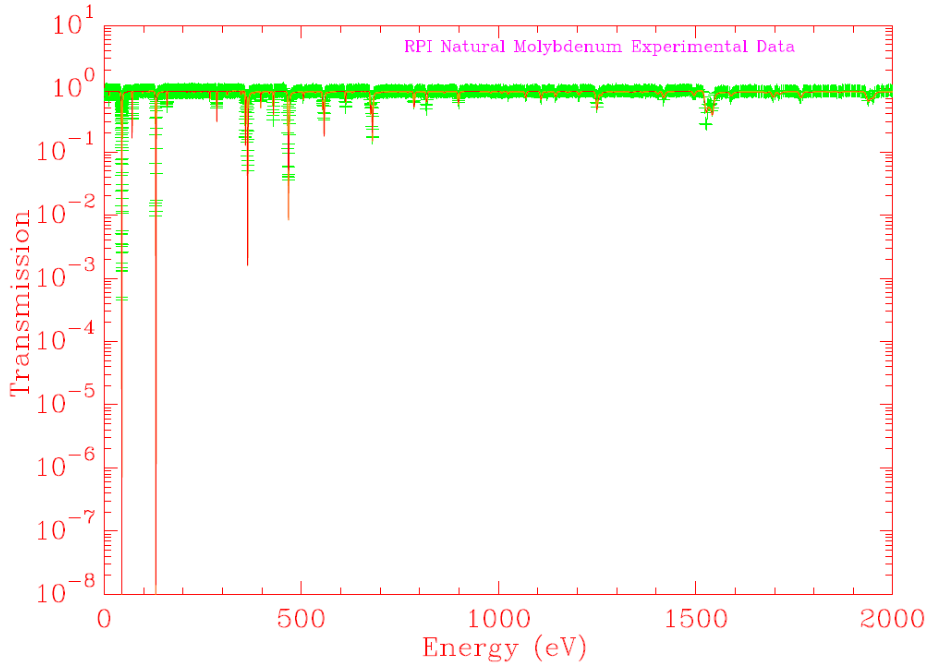

Figure 61) SAMMY fit to 2004 Natural Molybdenum Transmission Data

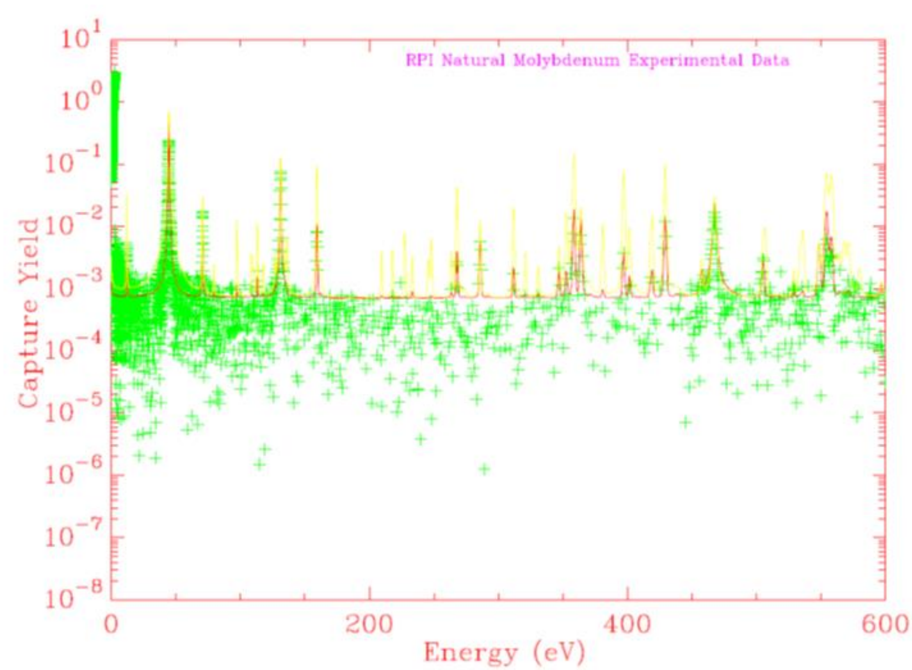

Figure 62) SAMMY fit to 1995 Natural Molybdenum Capture Data

Once this SAMMY fit was optimized to match the RPI experimentalists resonance parameter set, subsequent SAMMY runs were completed for each isotope of interest in which the resonance parameters in the energy region covered by both transmission and capture data are allowed to vary, i.e. 0-600 eV. This generates the experimental data covariance matrix *V*. Additionally, other sources of uncertainty, such as normalization, background, and resolution function are propagated using SAMMY's PUP (Propagated Uncertainty Parameter) feature. Finally, the experimental covariance matrix and PUP'ed uncertainty information is saved as the *Y* and *W* matrices detailed earlier in the description of SAMMY's Bayesian fitting scheme

Using the generated *Y* and *W* matrices, a final SAMMY run is completed with the option of generating ENDF formatted File 32 covariance data. This is resonance parameter-wise covariance data for the resonances varied in the 0-600 eV energy range. This energy range does not cover the entire resolved resonance region for any of the natural molybdenum isotopes. However, for most isotopes, it does capture the effects of the large low lying resonances. While this does not result in a perfect representation of the resonance-wise covariance data, it does produce the best possible set of covariance data given the experimental data available. An example is given below in figure 63 for ^{97}Mo.

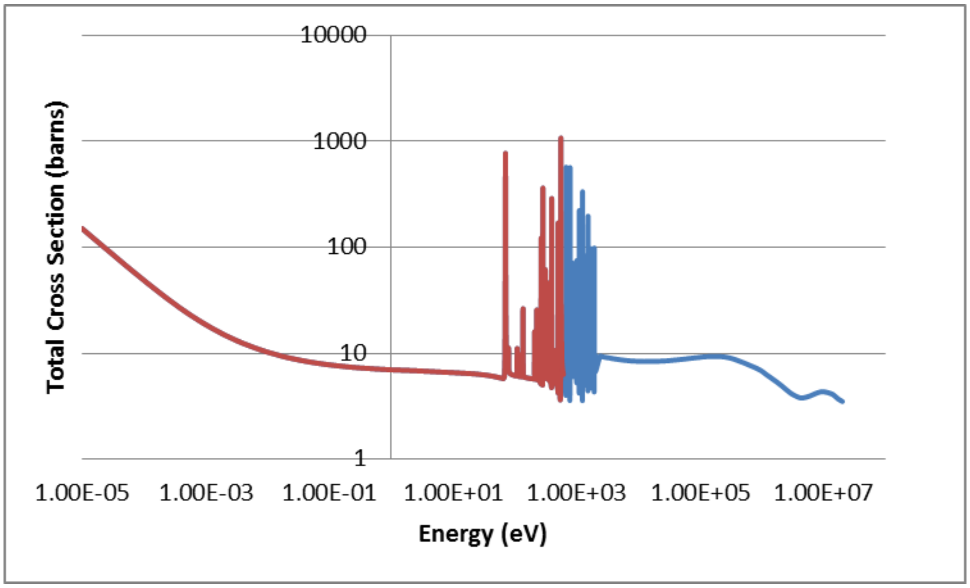

Figure 63) ENDF/B-VII.1 ^{97}Mo Total Cross Section, 0-600 eV highlighted

In order to visualize the resonance parameter covariance data produced by the retroactive method of SAMMY, it is helpful to convert it to group-wise covariance data. Flux weighted group cross-sections are defined as:

$$\bar{\sigma}_{xg}\Phi_g = \int_{E_g}^{E_{g+1}} \sigma_x(E)\Phi(\mathrm{E})\mathrm{dx} \tag{28}$$

Where

$$\Phi_g = \int_{E_g}^{E_{g+1}} \Phi(\mathrm{E})\mathrm{dx} \tag{29}$$

Φ_g is the neutron flux in group g, and $\bar{\sigma}_{xg}$ is the flux weighted group cross section for reaction x and group g. The corresponding group covariance matrix is calculated by taking the expectation value of the product of small increments in the group cross-section with respect to resonance parameters.

$$\overline{\delta\sigma}_{xg} = \sum_j \frac{\partial \sigma_{xj}}{\partial p_j} \delta p_j \tag{30}$$

$$\langle \overline{\delta\sigma}_{xg} \overline{\delta\sigma}_{xg'} \rangle = \sum_{jk} \frac{\partial\sigma_{xj}}{\partial p_j} \langle \delta p_j \delta p_k \rangle \frac{\partial\sigma_{xk}}{\partial p_k} \qquad (31)$$

In which

$$\langle \delta p_j \delta p_k \rangle = M'_{jk}$$

is the retroactive resonance parameter covariance matrix element for parameters j and k. [35]

Such a group-wise covariance matrix for the total cross-section in the resonance region of ^{97}Mo is plotted below in the SCALE 44 group structure as an example. It is compared with the covariance data currently available in ENDF/B-VII.1. Current covariance data assumes complete correlation between all energy regions, whereas the retroactively generated covariance data exhibits a much more detailed correlation structure. This is seen in the central images of figures 64 and 65. These correlation matrices contains values that can vary between -1 and 1, and record the degree to which the uncertainty in a given energy group is correlated with the uncertainty in all other energy groups. The uncertainty in each energy group is plotted above the correlation matrix in figures 64 and 65. The vector product of the uncertainty values and the correlation matrix yields the covariance matrix. Similar plots for total, capture, and elastic scattering for the natural isotopes of molybdenum are included in appendix A.

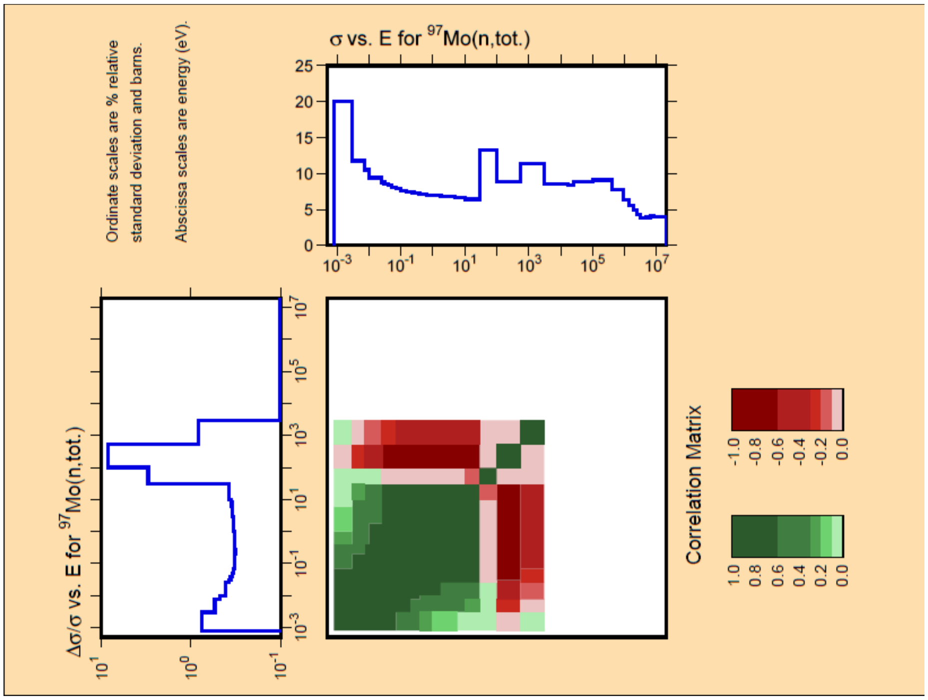

Figure 64) ^{97}Mo Total Retroactive Resolved Resonance Covariance

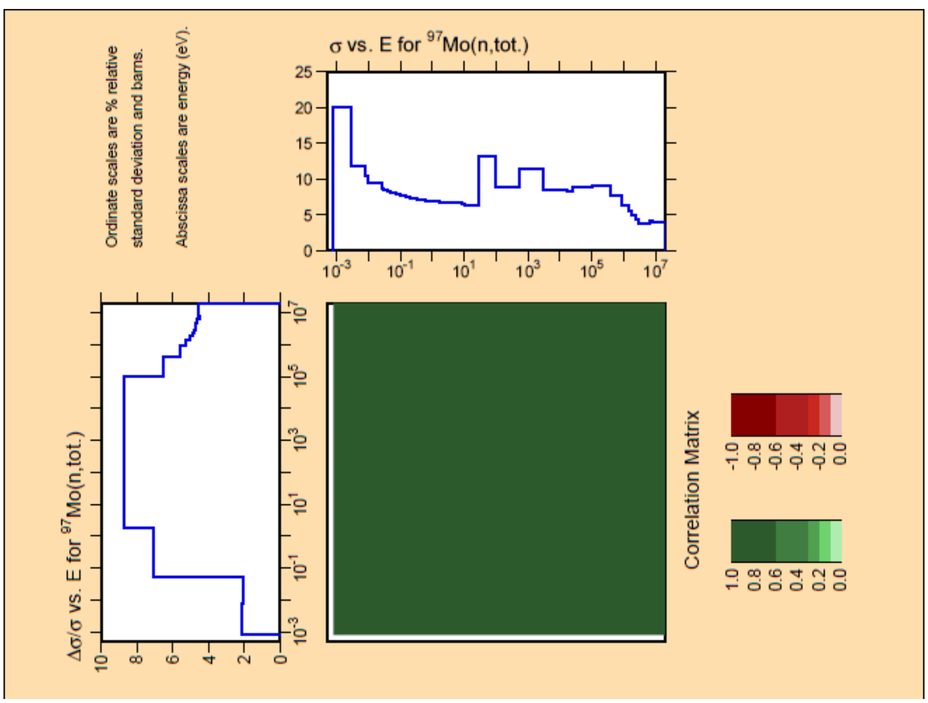

Figure 65) ^{97}Mo Total Current ENDF/B-VII.1 Covariance

FILE 33 FORMAT COVARIANCE DATA

Retroactively generated resonance parameter covariance matrices show significant improvement in correlation fidelity as compared to current covariance libraries which assume total correlation across all energy ranges. However, this covariance data often has low uncertainties, uncertainties that are often too low to be considered physical by end users, and are in fact below the minimum reasonable uncertainty values defined by the Cross Section Evaluation Working Group. [36] This low uncertainty can result from missing or unknown sources of uncertainty in the retroactive covariance generation process.

Additionally, by definition the resonance parameter covariance matrix only applies to the resolved resonance region as defined by its parameters. Other covariance data will be needed in the high energy region. The end goal then is to couple the high fidelity correlations of the retroactive resonance parameter covariance matrix with reasonable uncertainty values that will be accepted by end users, and to provide covariance data throughout all energy regions of interest.

To accomplish this, uncertainty data from three additional sources was incorporated: integral measurements at thermal and resonance energies, a dispersion analysis of select general use nuclear data libraries in the resonance region, and high energy covariances generated at Brookhaven National Laboratory using the Empire-KALMAN code.

Integral Measurement Uncertainty

Integral measurements' uncertainties are tabulated in the Atlas of Neutron Resonance Parameters and provide an additional connection with uncertainty data from experimental sources. The Atlas of Neutron Resonances Parameters is compiled by researchers at Brookhaven National Laboratory, and contains recommended cross-section resonance parameters drawn from all pertinent and available experimental sources. Evaluated neutron interaction data for all elements is included, along with uncertainties. The most important quantities included in the Atlas for this work are:

- Thermal cross-sections (total, capture) with uncertainties
- Scattering radii, with uncertainties
- Resonance integrals (capture), with uncertainties

These values can serve as a check of the reasonableness of calculated uncertainty data, as well as providing direct cross-section uncertainty data in the thermal energy region for evaluations with unreasonably low uncertainty.

Table 20 below summarizes key integral uncertainty values for the natural molybdenum isotopes.

Table 20) Integral Uncertainties for Natural Molybdenum Isotopes [37]

	2200 m/s Cross Section	Thermal Capture	Scattering Radius	Resonance Integral
^{92}Mo	2.33%	25.00%	2.86%	N/A
^{94}Mo	2.06%	17.65%	2.90%	N/A
^{95}Mo	5.70%	2.24%	2.86%	5.93%
^{96}Mo	1.86%	40.00%	2.88%	17.65%
^{97}Mo	2.12%	9.09%	2.90%	20.83%
^{98}Mo	2.20%	4.62%	2.90%	4.48%
^{100}Mo	2.11%	1.51%	2.90%	3.99%

In constructing file 33, values from the first three columns of table 1 were used as the diagonal values of the covariance matrix in the thermal energy region, from 10^{-5} eV to 0.05 eV, for total, capture, and scattering interaction cross-sections respectively for energy groups where the file 32 covariance data reported an uncertainty below the acceptable limits as defined by the Cross Section Evaluation Working Group.

Dispersion Method

The method described previously to generate the file 32 format covariances is based on a rigorous analytical fitting to the RPI experimental data. Such a fitting procedure produces improved cross-section values, but can frequently also produce low uncertainties and covariances. Such low covariances are often subject to questioning by end users. To address this issue, the National Nuclear Data Center has taken to considering the dispersion between evaluations when generating covariance libraries.

Dispersion methods consider the dispersion between evaluations as a further basis for uncertainty estimation. The concept is that the spread between independently evaluated cross-sections from the major data libraries reflect the true opinion of the international community of evaluators with respect to the cross-section precision. Low uncertainties are therefore expanded to reflect the spread between the major data libraries. [38][39][40] Advantages of this process include relative simplicity and ease of use, as well as considerable transparency. Practically, dispersion methods produce uncertainty estimates in line with the expectations of end users.

In order to complete a dispersion method analysis for the natural molybdenum isotopes, the 6 modern general use cross-section libraries available through the Nuclear

Energy Agency's online data bank were selected. Those libraries were ENDF/B-VII.1, JEFF-3.1.2, JENDL-4.0, RUSFOND-2010, CENDL-3.1, and TENDL2012.

Total, capture, and elastic scattering cross-sections for all natural isotopes of molybdenum from each of the above libraries were collapsed to the SCALE 44-group structure. The group-wise relative standard deviation across the independent evaluations was then calculated and were assigned as the diagonal values of the covariance matrix in the resonance energy region, from 0.05 eV to 25 keV, for their respective interactions where the file 32 covariance data reported an uncertainty below the acceptable limits as defined by the Cross Section Evaluation Working Group.

Empire-KALMAN High Energy Covariances

In the high energy region, model based covariances have been generated using the coupled Empire-KALMAN codes at Brookhaven National Laboratory. This code operates similarly to SAMMY, and generates covariance data based on parameters of high energy region interaction models. [41] EMPIRE includes a range of nuclear reaction models, such as the s the spherical optical model, Coupled Channels, Distorted Wave Born Approximation, Multi-step Direct, Multi-step Compound, the exciton model with preequilibrium emission of clusters and gamma rays, and the full featured Hauser-Feshbach(HF) model with multi-particle emission and detailed γ-cascade. KALMAN is a Bayesian code based on the theory of the Kalman filter, which can estimate covariances by combining experimental uncertainties and correlations with theory predictions. KALMAN calculates cross section covariances P in two steps: (i) the model parameter covariance matrix X is calculated from the experimental covariances V, and (ii) the error propagation is used to calculate cross section covariances P from the model parameter covariances X:

$$P = (X^{-1} + C^t V^{-1} C)^{-1} = X - XC^t(CXC^t + V)^{-1}CX \qquad (32)$$

where C is the sensitivity matrix describing response of the model to the perturbation of its parameters. To obtain the sensitivity matrix C EMPIRE is used to perturb 10-15 of the most relevant model parameters, such as optical model, level density, or preequilibrium strength, by roughly ±5% to determine their effect on the cross-sections for total, elastic, capture, etc. Sensitivity matrix elements are calculated from the change in a given cross section due to the change in a given model parameter. Model parameter uncertainties are adjusted to reproduce experimental cross-section uncertainties and covariance data.

This set of covariance data is the highest fidelity uncertainty data available for the high energy region of the molybdenum isotopes, and is currently included in ENDF/B-VII.1. The uncertainty values reported by BNL were assigned as the diagonal values of the covariance matrix in the high energy region, from 25 keV to 20 MeV.

Through combination of integral measurement uncertainty, dispersion method analysis, and the high energy covariances of the Empire-KALMAN code, a complete set of covariance data of reasonable magnitude spanning 10^{-5} eV to 20 MeV was generated for the natural molybdenum isotopes. Shown below in figure 66 and 67 as an example is the total cross-section for ^{97}Mo, again compared to the current ENDF/B-VII.1 covariance data. Correlation throughout the resonance region is strictly along the diagonal, as compared to the complete correlation assigned currently in ENDF/B-VII.1. Off diagonal correlation will be regained by combining the retroactively generated file 32 data with the diagonal file 33 data. Apparent correlation at thermal energies is due to round off error from NJOY processing. Similar plots for total, capture, and elastic scattering for the natural isotopes of molybdenum are included in appendix A.

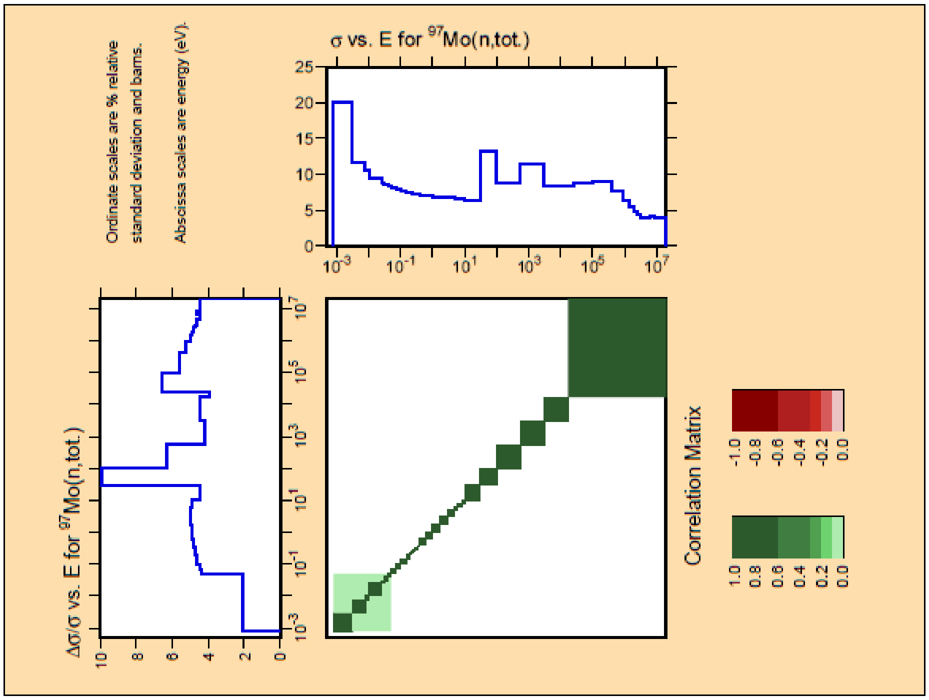

Figure 66) ^{97}Mo Total File 33 Covariance

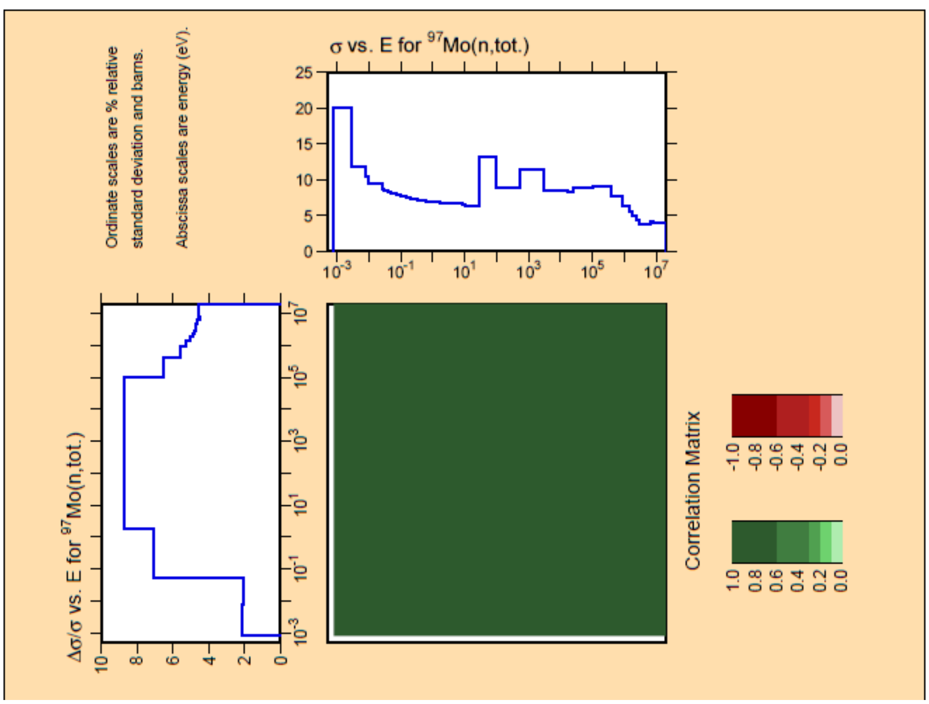

Figure 67) ^{97}Mo Total Current ENDF/B-VII.1 Covariance

Concluding Remarks

Currently only the ENDF/B-VII.1 nuclear data library includes cross-section covariance data for the natural molybdenum isotopes. However, this covariance data lacks meaningful correlation information as well as granularity in its diagonal uncertainty values. Using the retroactive method of SAMMY with experimental transmission and capture data for natural molybdenum, correlation in the resonance region between resonance parameters was regained, and this information was stored in ENDF File 32 format. Additionally, using a combination of integral measurement uncertainty, dispersion calculations between major library evaluation, and high energy covariances produced with the Empire-KALMAN code, a complete set of reasonable magnitude molybdenum isotope covariance data was produced for the energy range 10^{-5} eV to 20 MeV and was stored in ENDF File 33 format.

Figure 68 and 69 below compare the complete high fidelity covariance library (file 32 and file 33 combined) for ^{97}Mo to the current low fidelity covariance library available in ENDF/B-VII.1.

The combined file 32 and file 33 formatted covariance library for the molybdenum isotopes can now be used in sensitivity and uncertainty studies of the designed U-Moly foil fuel form critical experiments.

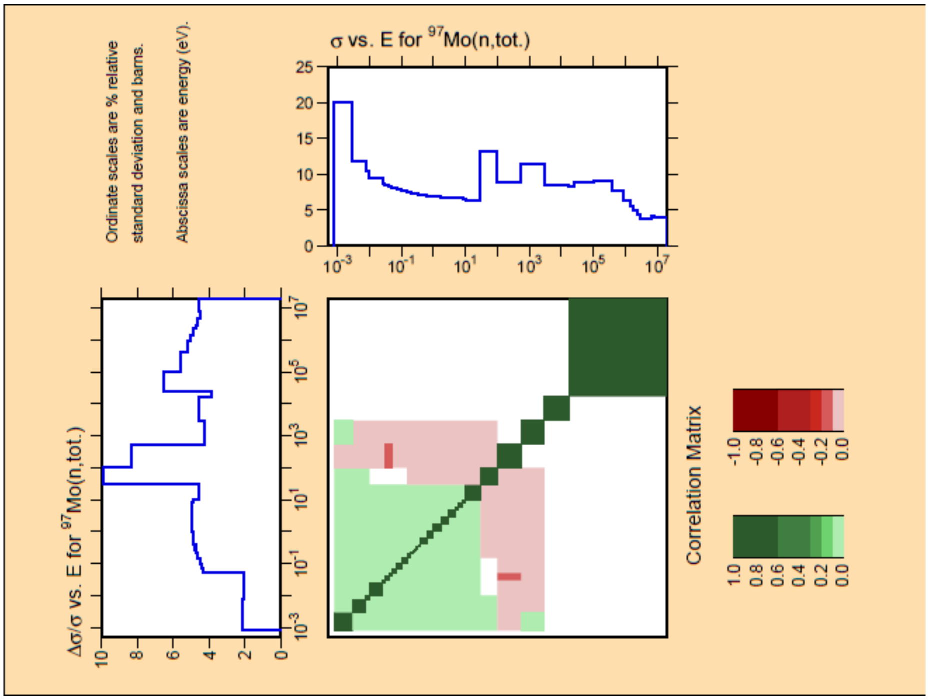

Figure 68) ^{97}Mo Total Cross Section CVDH Covariance Data

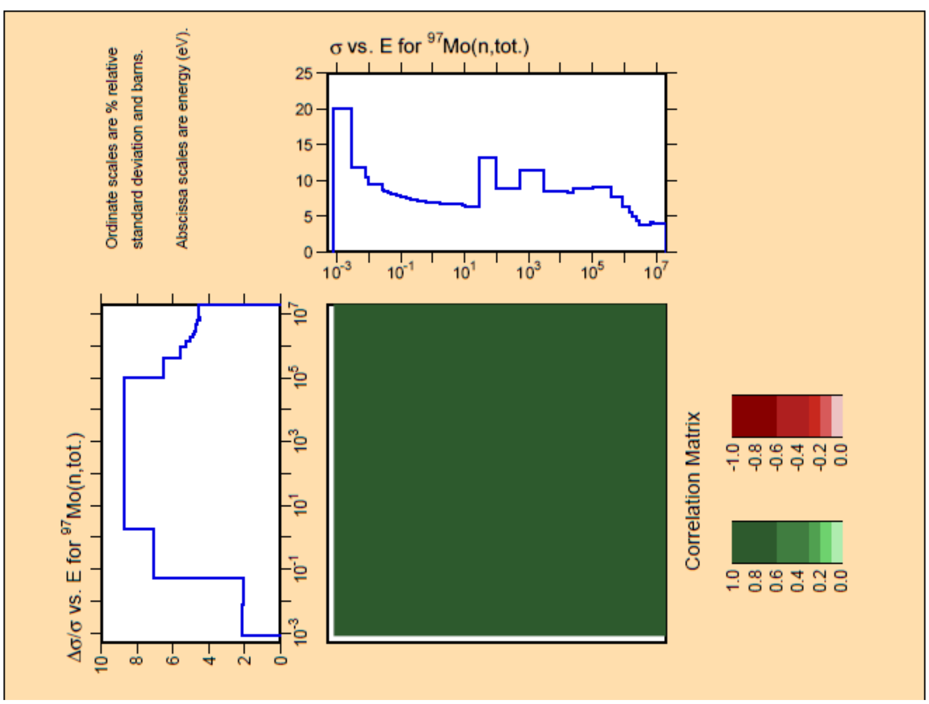

Figure 69) ^{97}Mo Total Cross Section LOFI Covariance Data

ANALYTICAL COMPARISON OF LOW FIDELITY AND HIGH FIDELITY MOLYBDENUM COVARIANCE DATA

Having constructed the improved fidelity molybdenum isotope covariance library, the final step is now to compare the accuracy of this covariance library to the existing low-fidelity library currently available. The designed U-Moly critical experiments offer a means to make such a comparison, using the TSURFER module of SCALE.

As before, the TSURFER module makes use of sensitivity profiles for modeled critical experiments generated by the TSUNAMI module of SCALE. These sensitivity profiles store the sensitivity of integral measurements, in this case multiplication factor, to changes in the group-wise cross-sections of the materials making up the critical experiment. TSURFER then calculates the set of cross-section changes, bounded by covariance data, which minimizes the difference between calculated and experimental reported multiplication factors across the critical experiments of interest.

However, in order to make a comparison between covariance libraries an additional capability of TSURFER is required. TSURFER makes a distinction between “experiments”, for which both a calculated and experimental multiplication factor are known, and “applications” for which only calculated multiplication factor is known. The set of cross-section changes TSURFER calculates from the set of experiments can be applied to the set of applications, resulting in an updated multiplication factor, as well as a reported “bias,” the change in k_{eff} due to the cross-section changes which ultimately stem from the cross-section uncertainty reported in the covariance data. More accurate cross-section data and cross-section covariance data will result in an improved fit to experimental results as well as influencing the reported bias. Therefore covariance libraries can be compared based on the goodness-of-fit to experimental results as well as the bias reported by TSURFER.

Cross-section and Covariance Processing

The high fidelity molybdenum covariance library generated is tied to the set of resonance parameters reported by the RPI experimentalists through the file 32 covariances. The first step was to incorporate those resonance parameters and covariance information into an ENDF file.

As before, ENDF/B-VII.1, JEFF 3.1.1, and JENDL 4.0 evaluated nuclear data files were selected as the basis for the molybdenum nuclear data. The RPI experimental resonance parameters, file 32 and file 33 covariance data for total, elastic scattering, and capture reactions were inserted into the appropriate data files. Additionally, the low fidelity covariance data for the threshold reactions of inelastic scattering and (n,2n) was inserted into the JEFF 3.1.1 and JENDL 4.0 nuclear data files in order to ensure a one-to-one comparison with the ENDF/B-VII.1 nuclear data files, which already included this covariance data.

After combining the nuclear data files with the RPI resonance parameters and high fidelity covariance data, the cross-section data processing code AMPX was used to generate cross-section and covariance libraries for the SCALE analysis code. The SCALE module TSUNAMI was then used to regenerate the sensitivity profiles for the molybdenum sensitive critical experiments from the ICSBEP and the ORNL FBR program for each of the evaluated nuclear data libraries. The SCALE module TSURFER was then used with the regenerated sensitivity profiles and ENDF, JEFF, and JENDL based covariance libraries to calculate the goodness-of-fit between the calculated results using the cross-section data and the reported experimental results.

TSURFER reports its goodness-of-fit metric in terms of the value of chi squared per degree of freedom. In order to maintain consistency across the set of experimental data, the SCALE manual recommends a maximum chi squared value per degree of freedom of 1.2. This sets the bounds of possible cross-section adjustment in terms of the cross-section covariance data. In order to achieve this maximum chi squared value, TSURFER eliminates experimental responses until chi squared per degree of freedom is less than 1.2. The individual experimental responses make up the degrees of freedom.

In order to ensure a one to one comparison between the three sets of cross-section and covariance data three initial TSURFER runs were completed with the respective data sets and the recommended chi squared limit of 1.2. Using the JENDL based data resulted in the most degrees of freedom (experimental responses considered) while not exceeding the limit on chi squared. The limit on chi squared was then relaxed for the ENDF and JEFF data sets until all three data sets utilized the same set of experimental responses. Table 21 below compiles the goodness-of-fit results of the described TSURFER runs.

Table 21) χ^2 for ENDF, JEFF, and JENDL

	ENDF	JEFF	JENDL
χ^2 per degree of freedom	2.336E+00	2.707E+00	1.195E+00

Based on its closest fit to the experimental data, JENDL 4.0 was selected as the basis for the cross-section and covariance data moving forward.

Goodness-of-Fit and Bias Comparison

Making comparisons of covariance data sets can be challenging, especially in cases where differences in cross-section data are also present. In the case at hand, cross-section differences in the form of the RPI resonance parameters play a role. If the RPI resonance parameters are assumed to be superior to the current set of resonance parameters in ENDF/B-VII.1 (unchanged from ENDF/B-VII.0, and used in the default SCALE 238 group library), then calculated multiplication factors should better match reported experimental values, and TSURFER should report a reduced bias, regardless of covariance data used. Similarly, if the high-fidelity covariance data is a more accurate reflection of the general uncertainty associated with molybdenum cross-section data then TSURFER should report a reduced bias when the high-fidelity covariance data is used, regardless of cross-section data. However, this assumption may be complicated by the fact that the high-fidelity covariance data is tied to the RPI resonance parameters through the file 32 covariance data. Finally, when both the superior cross-section data (RPI resonance parameters) and high fidelity covariance data is used, the reported bias should be the least as compared to all other combinations of cross-section and covariance data. Tables 22 through 25 below summarize the TSURFER bias results for the possible combinations discussed above.

Table 22) TSURFER bias: ENDF/B-VII.1 cross-sections and low fidelity covariance data

NAME	***CALCULATED k_{eff} VALUE***	***INITIAL STANDARD DEVIATION***	***ADJUSTED k_{eff} VALUE***	***ADJUSTED STANDARD DEVIATION***	***EFFECTIVE BIAS***	***ABSOLUTE BIAS***
Fast Bare	9.9779E-01	1.07E-02	9.9953E-01	2.77E-03	-1.74E-03	1.20E-02
Fast Reflected	9.9870E-01	2.04E-02	1.0121E+00	5.09E-03	-1.34E-02	1.75E-02
Thermal Standard	9.9871E-01	4.89E-03	9.9874E-01	2.12E-03	-3.48E-05	8.03E-03
Thermal Max	9.9687E-01	5.96E-03	9.9632E-01	4.17E-03	5.50E-04	5.65E-03

Table 23) TSURFER bias: ENDF/B-VII.1 cross-sections and high fidelity covariance data

NAME	***CALCULATED k_{eff} VALUE***	***INITIAL STANDARD DEVIATION***	***ADJUSTED k_{eff} VALUE***	***ADJUSTED STANDARD DEVIATION***	***EFFECTIVE BIAS***	***ABSOLUTE BIAS***
Fast Bare	9.9779E-01	1.07E-02	9.9967E-01	2.77E-03	-1.88E-03	1.28E-02
Fast Reflected	9.9870E-01	2.04E-02	1.0133E+00	4.98E-03	-1.46E-02	1.89E-02
Thermal Standard	9.9871E-01	4.89E-03	9.9878E-01	2.12E-03	-7.00E-05	7.94E-03
Thermal Max	9.9687E-01	5.96E-03	9.9654E-01	2.75E-03	3.36E-04	5.32E-03

Table 24) TSURFER bias: RPI resonance parameters and low fidelity covariance data

NAME	***CALCULATED k_{eff} VALUE***	***INITIAL STANDARD DEVIATION***	***ADJUSTED k_{eff} VALUE***	***ADJUSTED STANDARD DEVIATION***	***EFFECTIVE BIAS***	***ABSOLUTE BIAS***
Fast Bare	9.9795E-01	1.07E-02	1.0001E+00	2.80E-03	-2.13E-03	3.64E-03
Fast Reflected	9.9860E-01	2.03E-02	9.9805E-01	4.88E-03	5.57E-04	3.72E-03
Thermal Standard	9.9828E-01	4.91E-03	1.0029E+00	2.13E-03	-4.66E-03	4.07E-03
Thermal Max	9.9765E-01	5.11E-03	1.0014E+00	4.22E-03	-3.76E-03	4.63E-03

Table 25) TSURFER bias: RPI resonance parameters and high fidelity covariance data

NAME	***CALCULATED k_{eff} VALUE***	***INITIAL STANDARD DEVIATION***	***ADJUSTED k_{eff} VALUE***	***ADJUSTED STANDARD DEVIATION***	***EFFECTIVE BIAS***	***ABSOLUTE BIAS***
Fast Bare	9.9795E-01	1.07E-02	1.0001E+00	2.80E-03	-2.17E-03	3.71E-03
Fast Reflected	9.9860E-01	2.03E-02	9.9803E-01	4.75E-03	5.77E-04	3.74E-03
Thermal Standard	9.9828E-01	4.91E-03	1.0029E+00	2.13E-03	-4.65E-03	3.98E-03
Thermal Max	9.9765E-01	5.11E-03	1.0015E+00	2.78E-03	-3.82E-03	4.59E-03

Tables 22 through 25 list effective and absolute bias values for each proposed critical experiment design. The effective bias is the sum of all the biases from the individual isotope, reaction pairs possible in the experiment. The signs for these biases can be positive or negative, and can therefore cancel each other out in the effective bias. The absolute bias is the sum of the absolute values of the individual biases. For ease of comparison, figure 70 below compiles the last column of tables 22 through 25.

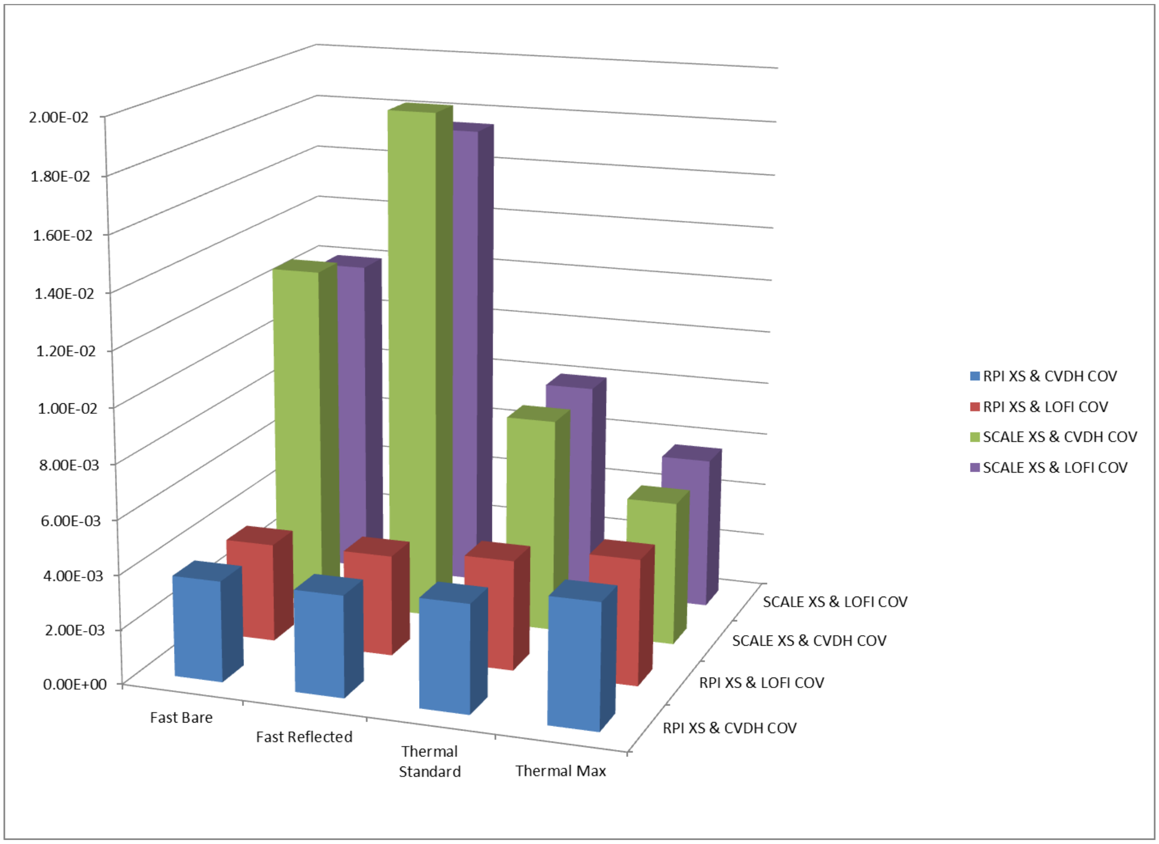

Figure 70) Absolute Bias Comparison across Experiment Designs and Nuclear Data Sets

As can be seen in figure 70, there is generally a reduction in bias when the JENDL based cross section data is used, indicating that the combination of RPI resonance parameters and JENDL cross-section data is an improvement on the ENDF/B-VII.1 data. The comparison of covariance libraries is less clear cut, for the fast spectrum results the bias is slightly greater for the low fidelity covariance data set, while for the thermal spectrum cases bias is reduced for the high fidelity covariance case. To reiterate: only the initial molybdenum isotope cross-section data and covariance data varies among the above cases, all other cross-section and covariance data is constant.

To gain a clearer understanding of the effects of the high fidelity covariance data on molybdenum associated biases, tables 26 through 29 and figures 71 through 74 below compile the total absolute bias for each molybdenum isotope for each combination of cross-section and covariance data for each proposed critical experiment design. In all cases and for all the molybdenum isotopes the absolute bias is reduced when the high fidelity covariance data is used in conjunction with the RPI resonance parameters as compared to the current cross-section data and covariance data. Additionally, for a clear majority of the molybdenum isotopes across the four experiment designs the absolute bias is reduced when the RPI resonance parameters are used in conjunction with the high fidelity covariance data as compared to the current low fidelity data.

Table 26) Total Bias for Molybdenum Isotopes for Fast Bare Critical Experiment Design

	RPI XS & CVDH COV	RPI XS & LOFI COV	ENDF/B-VII.1 & CVDH COV	ENDF/B-VII.1 & LOFI COV
^{92}Mo	7.47E-06	8.23E-06	8.79E-06	9.64E-06
^{94}Mo	2.45E-06	3.01E-06	6.39E-06	4.65E-06
^{95}Mo	2.15E-05	5.27E-05	3.68E-05	3.40E-05
^{96}Mo	1.07E-05	1.07E-05	2.10E-05	1.57E-05
^{97}Mo	2.45E-05	4.01E-05	2.36E-05	2.38E-05
^{98}Mo	1.31E-05	1.27E-05	3.01E-05	2.24E-05
^{100}Mo	2.96E-06	2.79E-06	4.28E-06	3.51E-06
All Mo	8.26E-05	1.30E-04	1.31E-04	1.14E-04

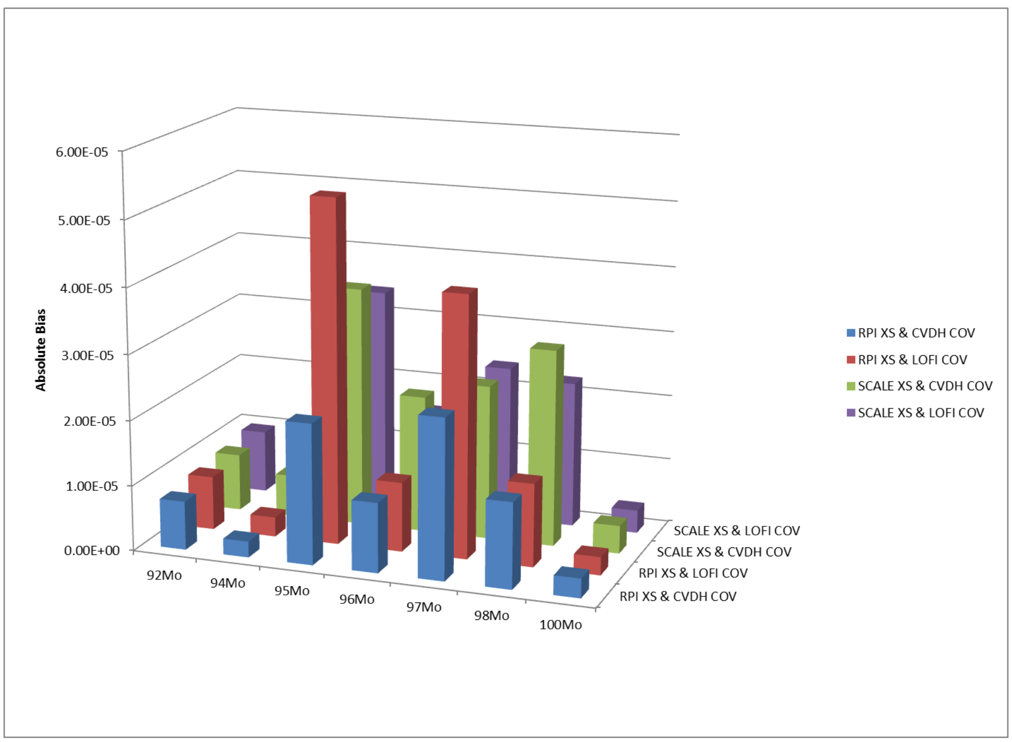

Figure 71) Molybdenum Isotope Bias Comparison across Nuclear Data Sets for Fast Bare Critical Experiment Design

Table 27) Total Bias for Molybdenum Isotopes for Fast Reflected Critical Experiment

	RPI XS & CVDH COV	RPI XS & LOFI COV	ENDF/B-VII.1 & CVDH COV	ENDF/B-VII.1 & LOFI COV
^{92}Mo	4.34E-06	4.40E-06	1.38E-05	1.71E-05
^{94}Mo	1.50E-06	1.75E-06	1.15E-05	7.41E-06
^{95}Mo	8.87E-06	1.48E-05	9.55E-05	1.17E-04
^{96}Mo	6.12E-06	6.73E-06	3.40E-05	3.06E-05
^{97}Mo	7.03E-06	1.11E-05	9.11E-05	1.06E-04
^{98}Mo	9.29E-06	9.83E-06	3.10E-05	2.68E-05
^{100}Mo	2.30E-06	2.39E-06	2.16E-06	2.38E-06
All Mo	3.95E-05	5.10E-05	2.79E-04	3.08E-04

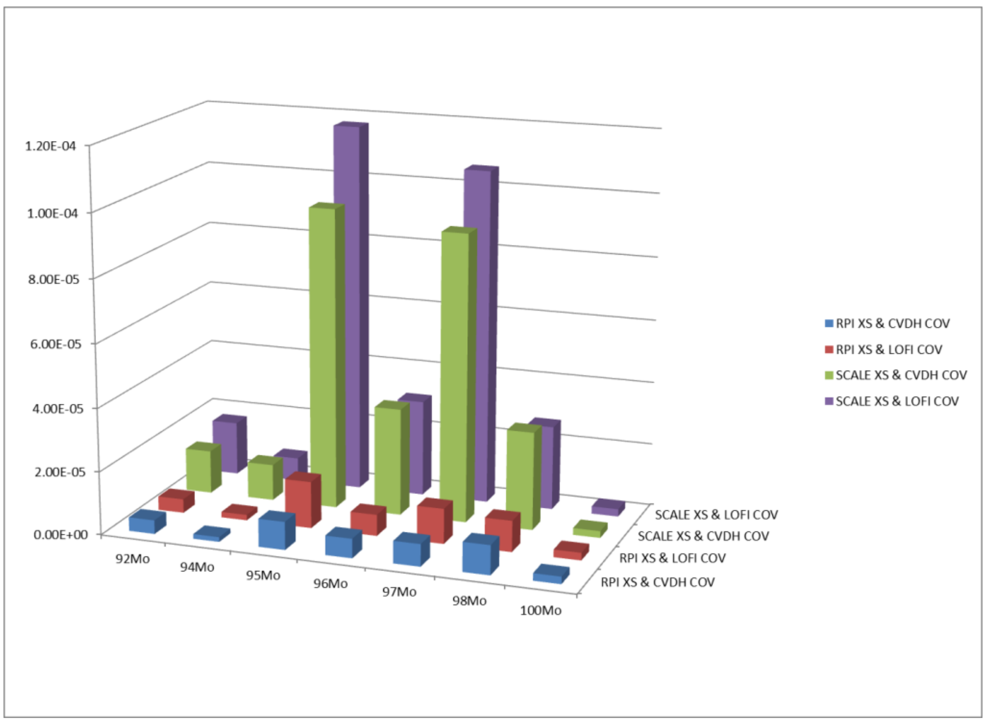

Figure 72) Molybdenum Isotope Bias Comparison across Nuclear Data Sets for Fast Reflected Critical Experiment Design

Table 28) Total Bias for Molybdenum Isotopes for Thermal Standard Critical Experiment

	RPI XS & CVDH COV	RPI XS & LOFI COV	ENDF/B-VII.1 & CVDH COV	ENDF/B-VII.1 & LOFI COV
^{92}Mo	1.06E-06	1.34E-06	2.24E-06	3.89E-06
^{94}Mo	3.42E-07	3.21E-07	2.74E-06	1.78E-06
^{95}Mo	3.19E-06	1.11E-05	4.24E-05	6.97E-05
^{96}Mo	4.55E-06	5.67E-06	2.74E-05	3.35E-05
^{97}Mo	6.05E-07	8.43E-06	2.64E-05	4.77E-05
^{98}Mo	2.36E-06	1.61E-06	1.27E-05	1.02E-05
^{100}Mo	5.98E-07	1.17E-07	2.72E-06	2.41E-06
All Mo	1.27E-05	2.86E-05	1.16E-04	1.69E-04

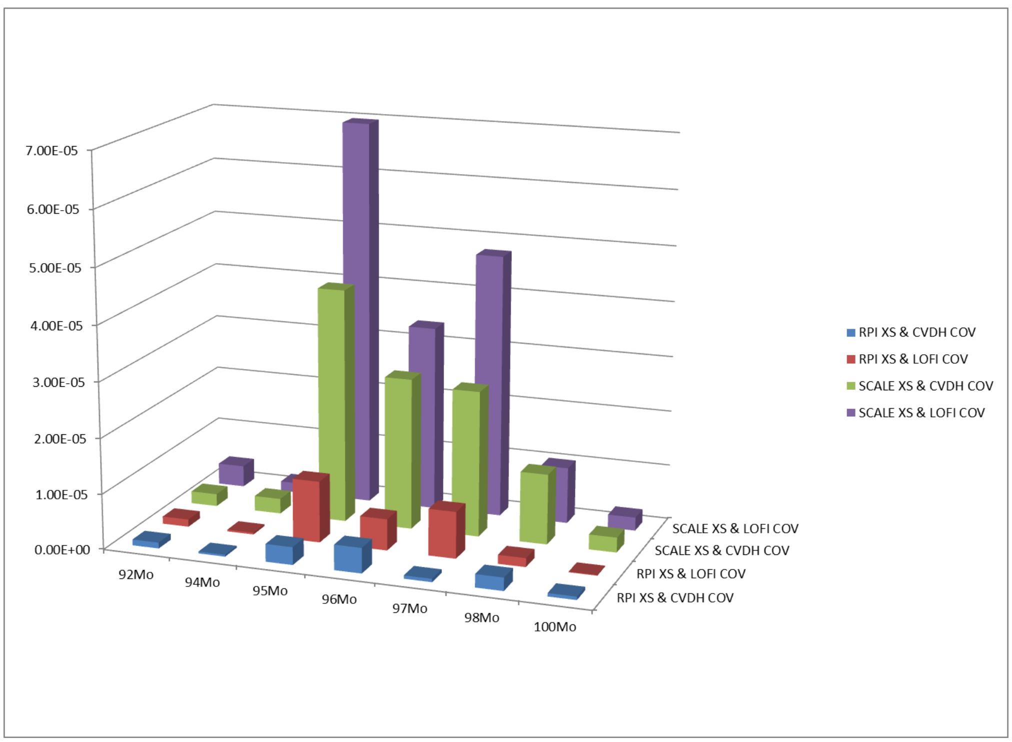

Figure 73) Molybdenum Isotope Bias Comparison across Nuclear Data Sets for Thermal Standard Critical Experiment Design

Table 29) Total Bias for Molybdenum Isotopes for Thermal Max Critical Experiment

	RPI XS & CVDH COV	RPI XS & LOFI COV	ENDF/B-VII.1 & CVDH COV	ENDF/B-VII.1 & LOFI COV
^{92}Mo	2.97E-05	2.56E-05	2.27E-05	3.19E-05
^{94}Mo	7.46E-06	8.10E-06	2.97E-05	1.44E-05
^{95}Mo	1.77E-05	5.35E-05	2.16E-04	3.47E-04
^{96}Mo	3.23E-05	3.44E-05	1.03E-04	1.45E-04
^{97}Mo	1.51E-05	2.28E-05	1.87E-04	3.08E-04
^{98}Mo	4.62E-05	4.70E-05	1.10E-04	7.54E-05
^{100}Mo	1.02E-05	1.05E-05	2.08E-05	1.45E-05
All Mo	1.59E-04	2.02E-04	6.89E-04	9.36E-04

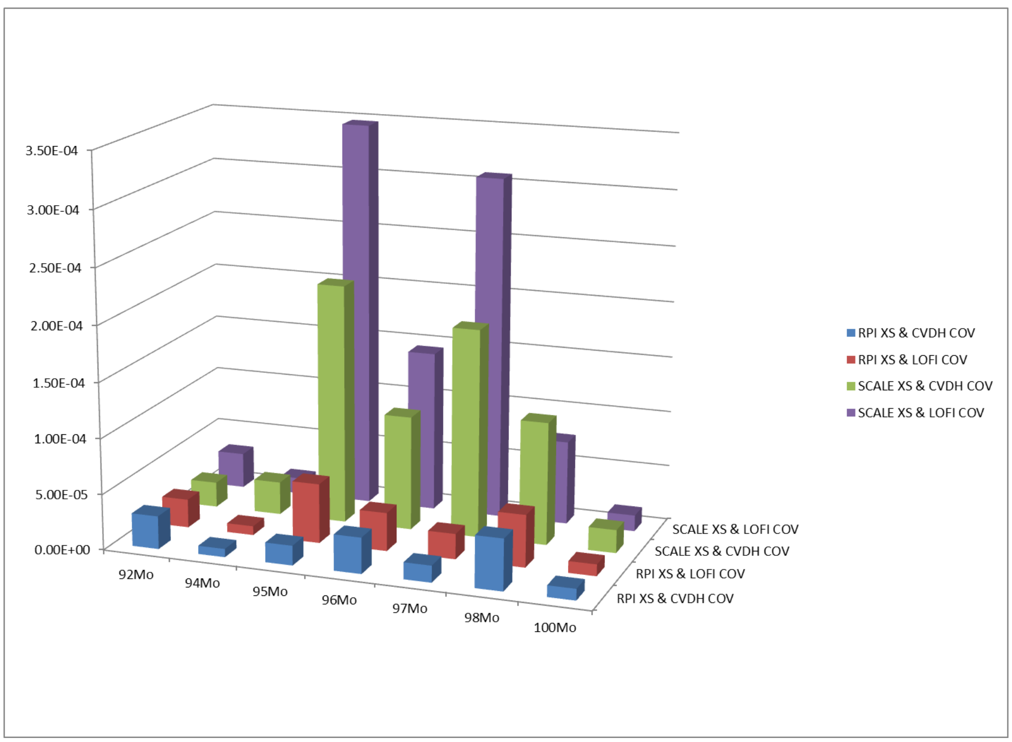

Figure 74) Molybdenum Isotope Bias Comparison across Nuclear Data Sets for Thermal Max Critical Experiment Design

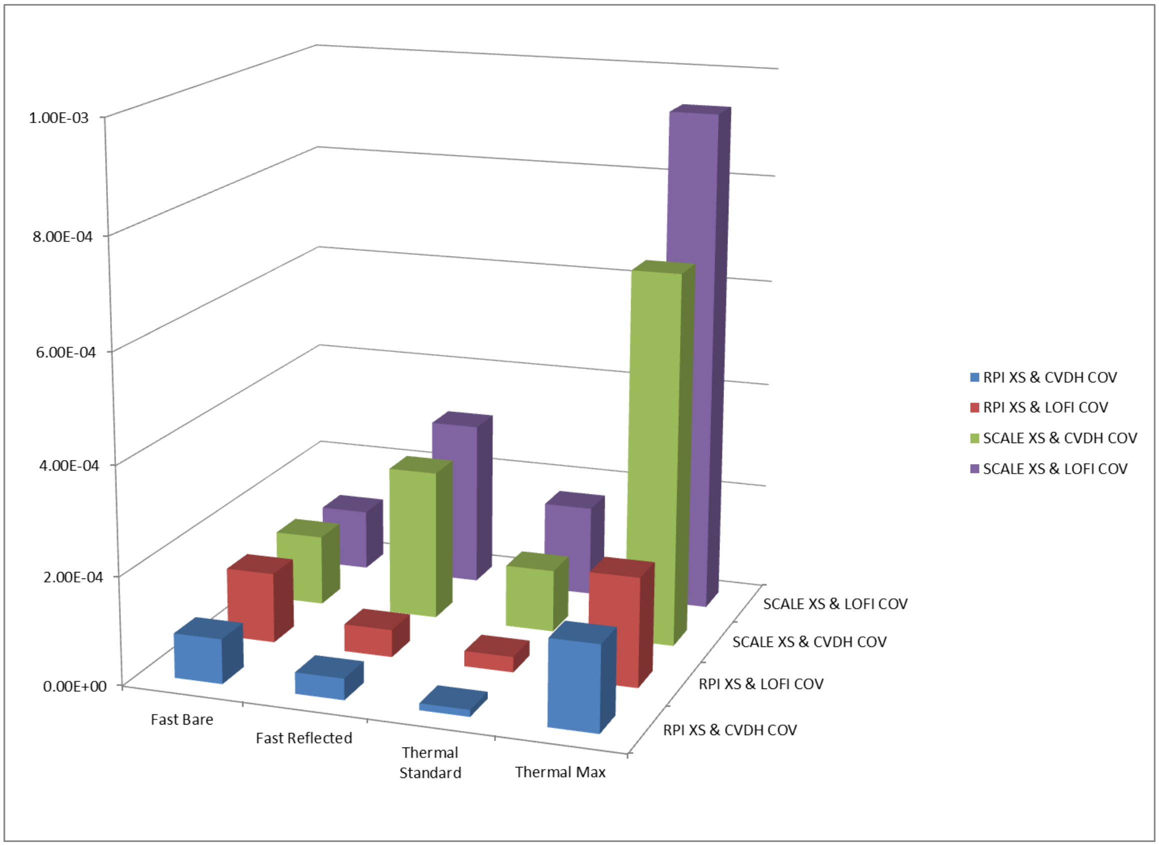

Figure 75) Total Molybdenum Bias

Finally, figure 75 above displays the total absolute bias for elemental molybdenum across the four proposed critical experiment designs and four combinations of cross-section and covariance data. The clear trend is a reduction in bias associated with molybdenum due to the use of improved cross-section and covariance data.

While the above discussion of absolute biases is indeed indicative of improved covariance data, it would still be possible for reduced absolute biases to appear with poorer covariance data if the goodness of fit of the calculated to experimental results due to the cross-section changes generated by TSURFER was also degraded. Table 30 below gives the χ^2 per degree of freedom measure of goodness of fit as reported by TSURFER for the four possible combinations of cross-section data and covariance data. As seen with the absolute bias data, a significant improvement in goodness of fit is achieved through the improved cross section data, and another slight improvement to the goodness of fit is observed when both the improved cross-section data and high fidelity covariance data are used in conjunction.

Table 30) Goodness of Fit for Combinations of Cross-Section and Covariance Data

	JENDL/RPI XS & CVDH COV	JENDL/RPI XS & LOFI COV	ENDF/B-VII.1 & CVDH COV	ENDF/B-VII.1 & LOFI COV
χ^2 per degree of freedom	1.195E+00	1.197E+00	1.428E+00	1.379E+00

Cross Section Adjustment Comparisons

As discussed previously, the bias reported by TSURFER as being associated with a particular isotope and reaction derives from adjustments TSURFER makes to the cross-section for that isotope and reaction, constrained by the covariance data for that isotope.

Comparisons of the cross section adjustments TSURFER makes when using different cross section and covariance libraries, in the context of the reported overall goodness-of-fit, can help to distinguish advantages and disadvantages between the differing libraries.

Below are plots of TSURFER's cross section adjustments for each of the four combinations of cross section data and covariance data explored earlier in this chapter. Included isotopes and reactions are elastic scattering and neutron capture for the molybdenum isotopes, as well as all reported reactions for hydrogen, ^{235}U and ^{238}U.

Molybdenum Elastic Scattering

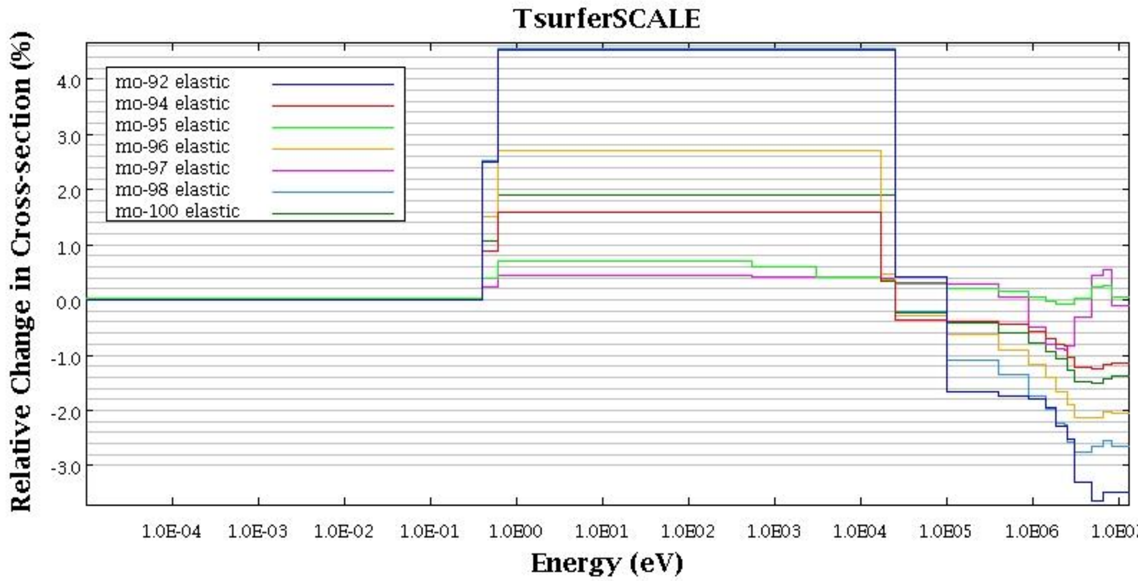

Figure 76) Cross Section Adjustment to Elastic Scattering of Molybdenum Isotopes for ENDF/B-VII.1 & LOFI Covariance

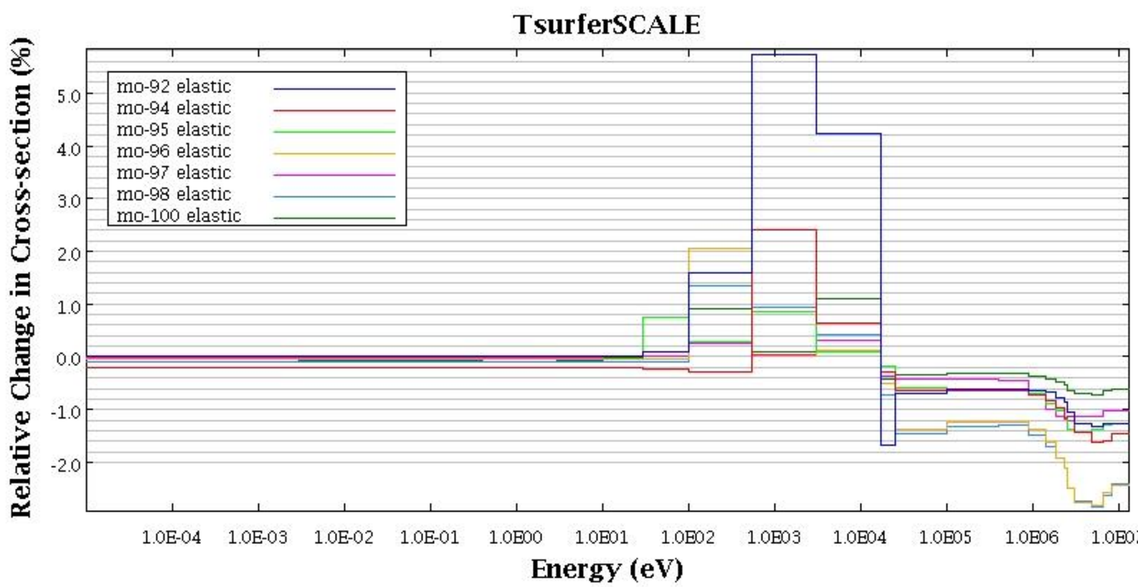

Figure 77) Cross Section Adjustment to Elastic Scattering of Molybdenum Isotopes for ENDF/B-VII.1 & CVDH Covariance

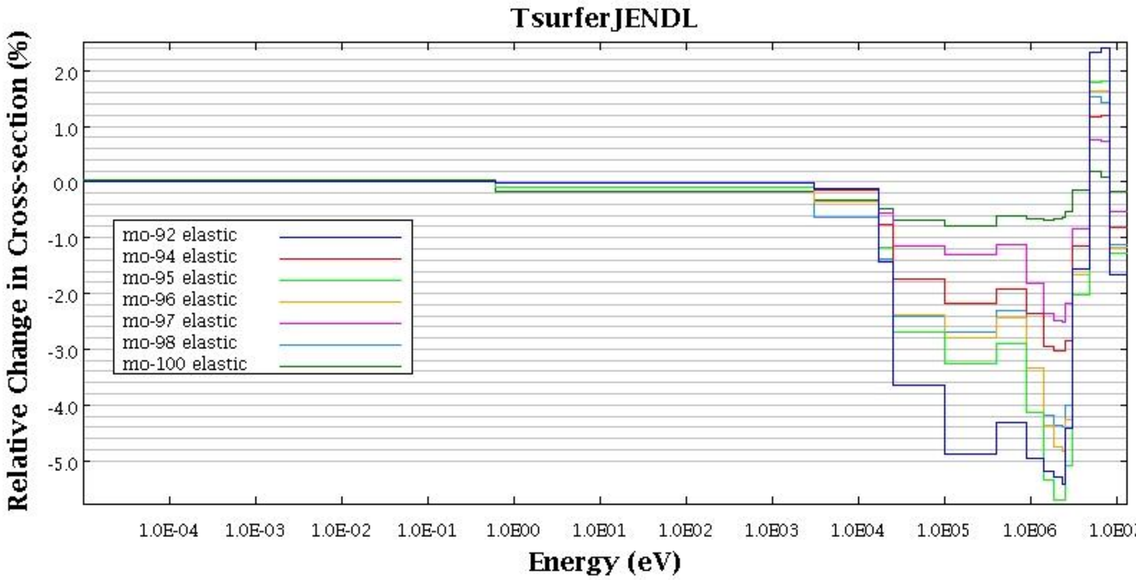

Figure 78) Cross Section Adjustment to Elastic Scattering of Molybdenum Isotopes for JENDL4.0 with RPI resonance parameters & LOFI Covariance

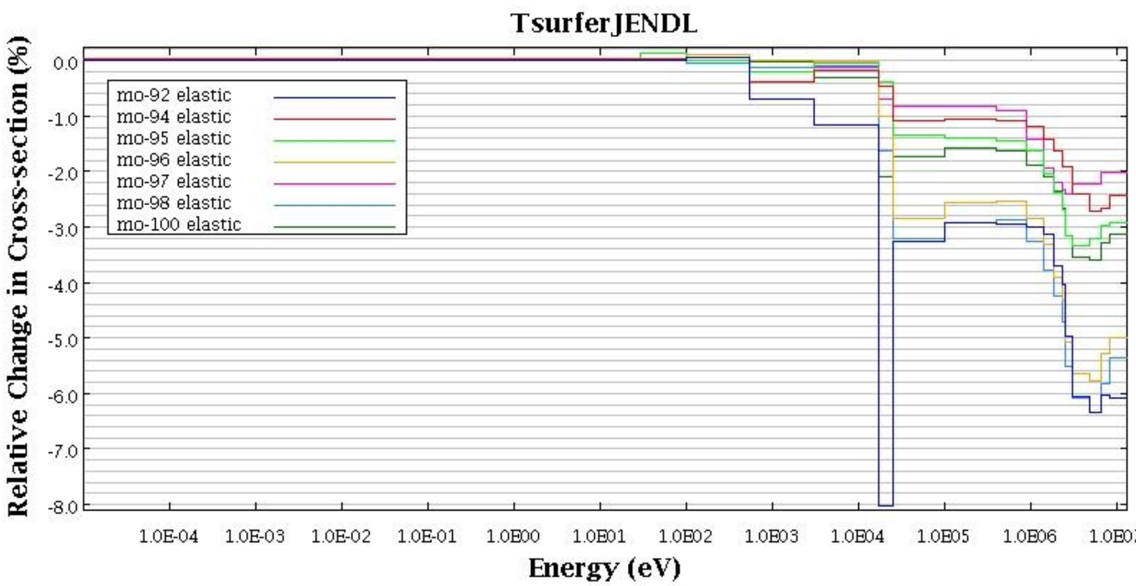

Figure 79) Cross Section Adjustment to Elastic Scattering of Molybdenum Isotopes for JENDL4.0 with RPI resonance parameters & CVDH Covariance

Comparing the cases in which the molybdenum isotope cross section data is pulled from ENDF/B-VII.1 (Figure 76 and 77) to the cases in which JENDL4.0 is used with the RPI resonance parameters (Figures 78 and 79), it appears less dramatic adjustments to the resonance region cross sections are required with latter set of data, potentially indicating the superiority of JENDL and the RPI resonance parameters in this energy region. All four cases seem to indicate that the high energy scattering cross sections may be high, with the most dramatic adjustment occurring when the JENDL and RPI cross section data is used with the new CVDH covariance library.

Molybdenum Capture

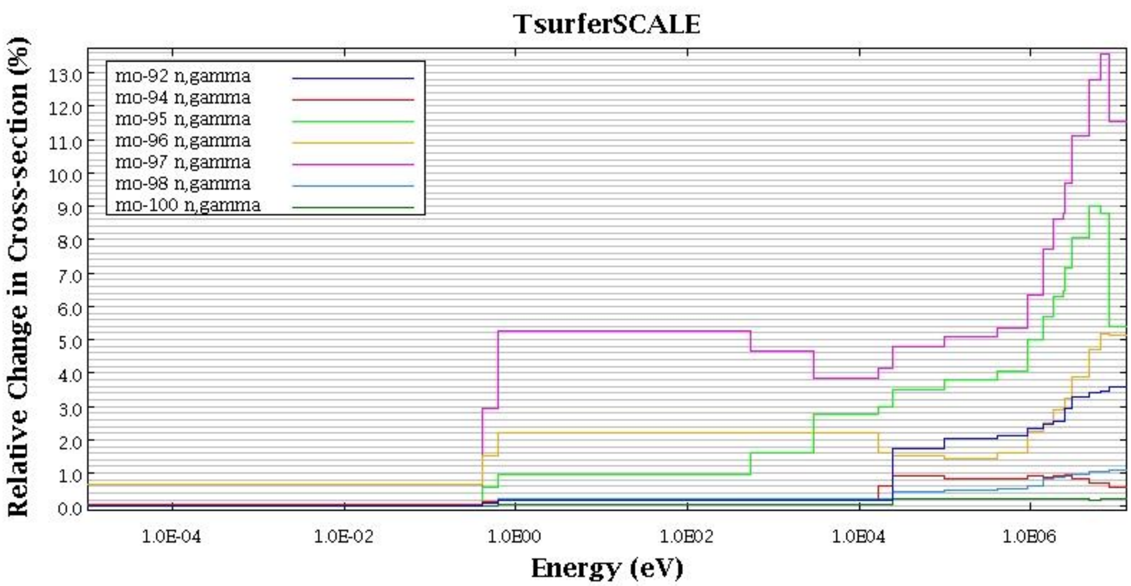

Figure 80) Cross Section Adjustment to Capture of Molybdenum Isotopes for ENDF/B-VII.1 & LOFI Covariance

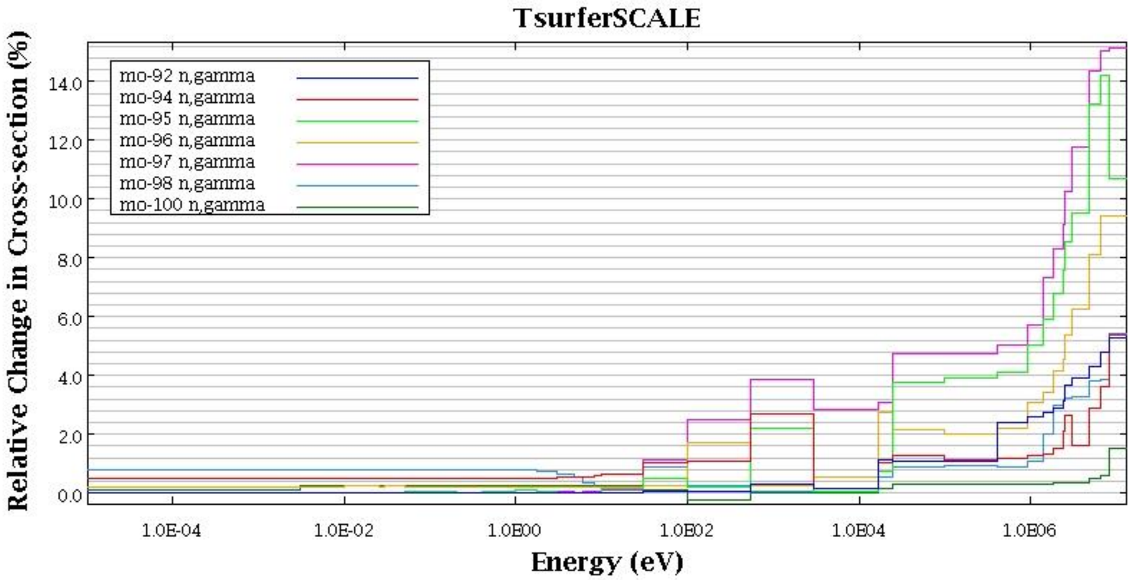

Figure 81) Cross Section Adjustment to Capture of Molybdenum Isotopes for ENDF/B-VII.1 & CVDH Covariance

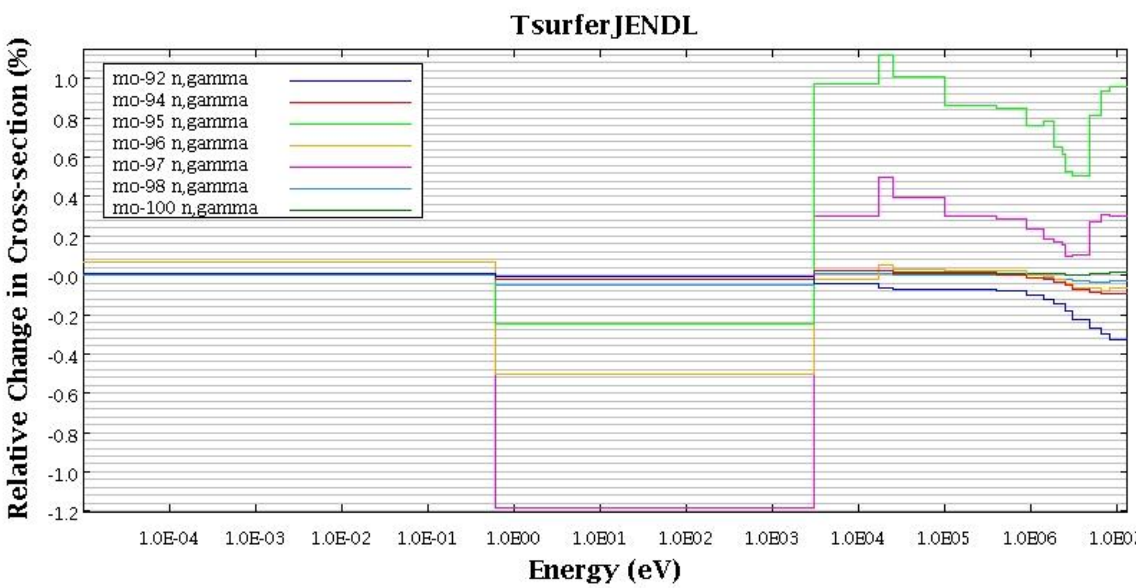

Figure 82) Cross Section Adjustment to Capture of Molybdenum Isotopes for JENDL4.0 with RPI resonance parameters & LOFI Covariance

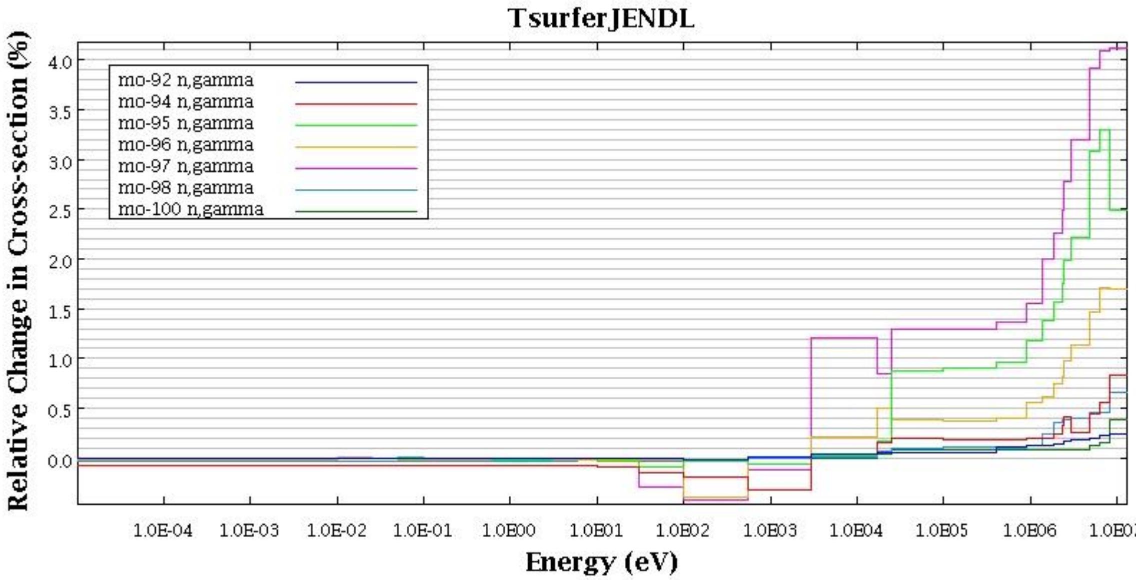

Figure 83) Cross Section Adjustment to Capture of Molybdenum Isotopes for JENDL4.0 with RPI resonance parameters & CVDH Covariance

Three of the four cases (figures 80, 81, and 83) indicate the high energy capture cross section may be low, though the use of ENDF/B-VII.1 molybdenum cross section data results in significantly larger cross section adjustments. Use of the current low fidelity covariance data (figures 80 and 82) also results in cross section adjustments in the resonance region that are not seen when using the new CVDH covariance library.

Hydrogen

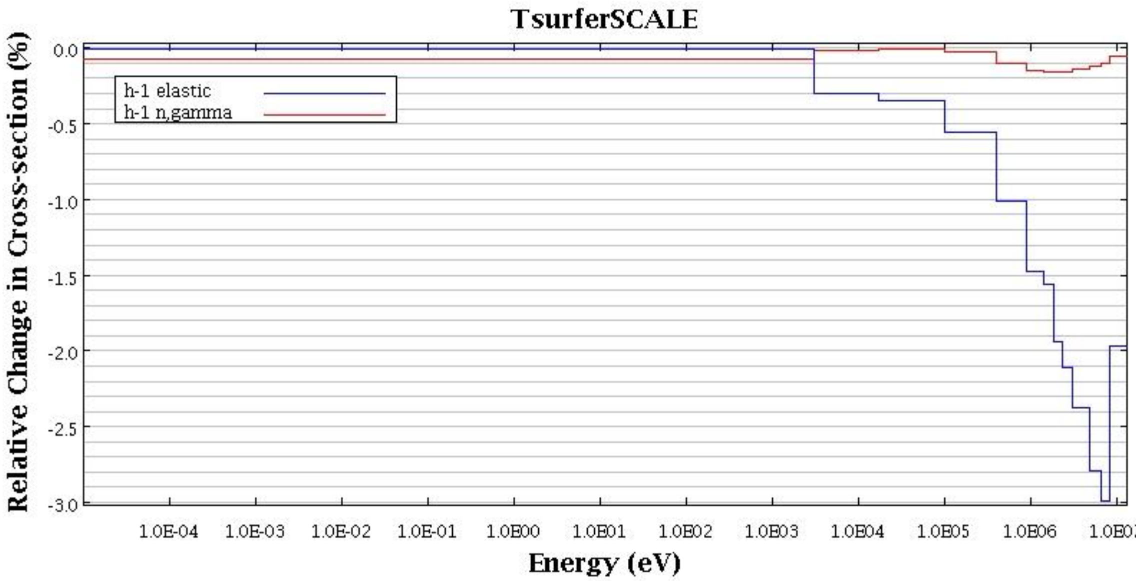

Figure 84) Cross Section Adjustment to Hydrogen for Molybdenum Cross Sections from ENDF/B-VII.1

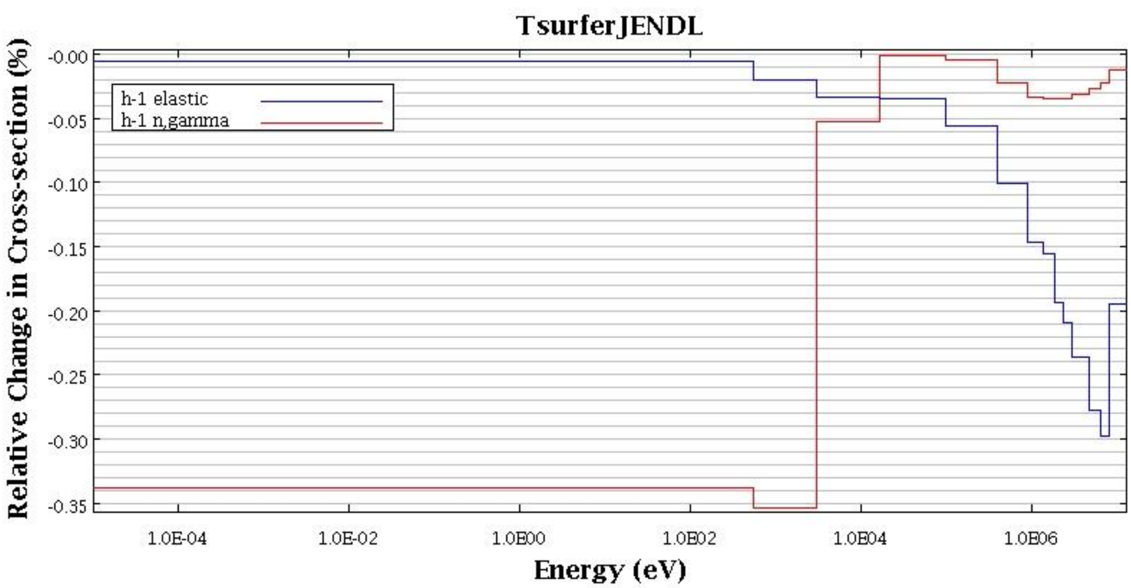

Figure 85) Cross Section Adjustment to Hydrogen for Molybdenum Cross Sections from JENDL4.0 with RPI Resonance Parameters

For isotopes other than molybdenum all cross section and covariance data is the same across all cases. Therefore differences between cases for isotopes other than molybdenum result from the system wide effects of the molybdenum cross sections changing from ENDF/B-VII.1 to JENDL 4.0 and RPI resonance parameters.

Some adjustment is recommended for the high energy hydrogen scattering cross section when molybdenum cross sections are drawn from ENDF/B-VII.1, however there are negligible adjustments to the hydrogen cross-section when molybdenum cross sections are provided by JENDL 4.0 and RPI resonance parameters. In each case bias due to hydrogen remains high.

^{238}U

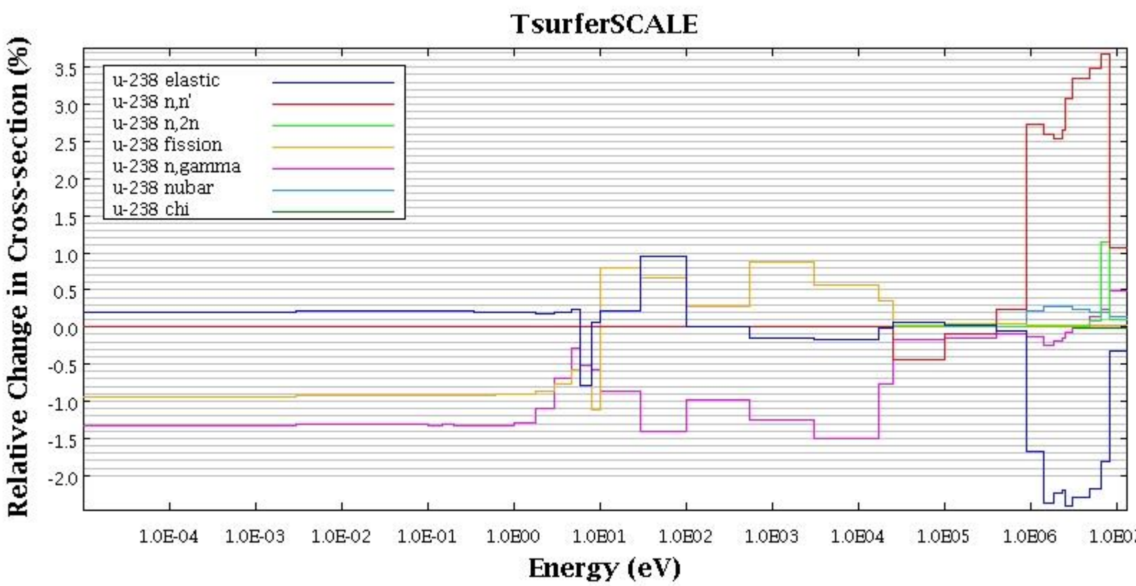

Figure 86) Cross Section Adjustment to ^{238}U for Molybdenum Cross Sections from ENDF/B-VII.1

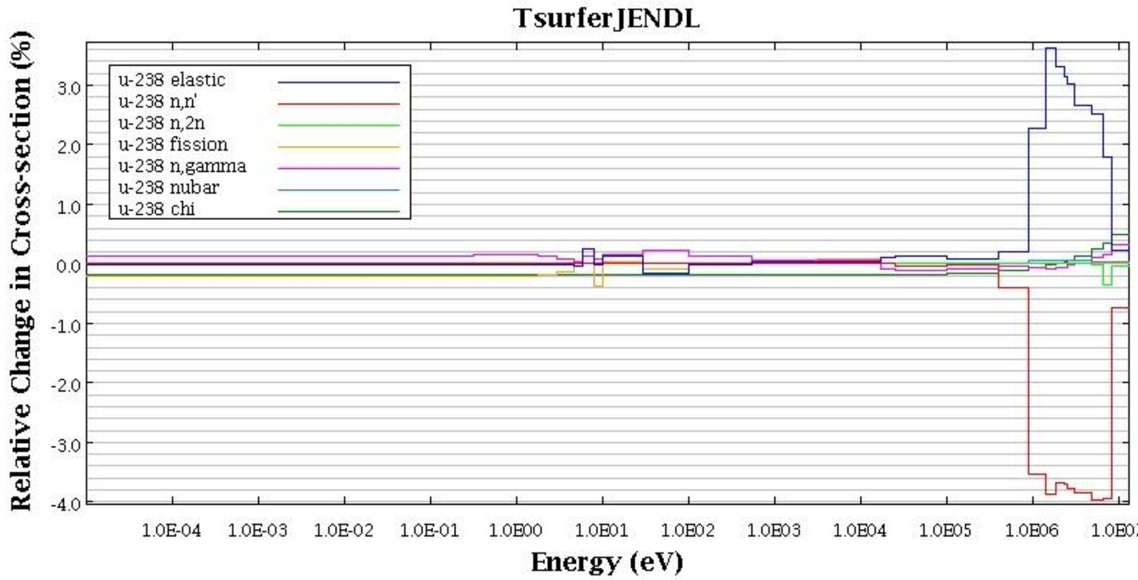

Figure 87) Cross Section Adjustment to ^{238}U for Molybdenum Cross Sections from JENDL4.0 with RPI resonance parameters

Significantly more cross section adjustment is seen for ^{238}U in the resonance region when molybdenum cross section data come from ENDF/B-VII.1, as well as significantly more attributed bias.

^{235}U

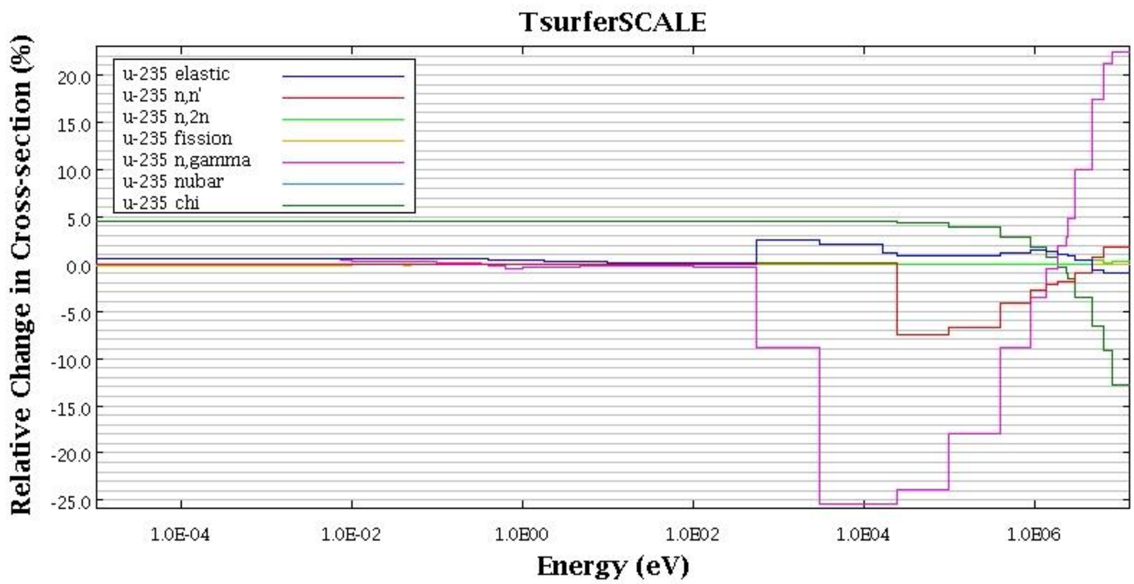

Figure 88) Cross Section Adjustment to ^{235}U for Molybdenum Cross Sections from ENDF/B-VII.1

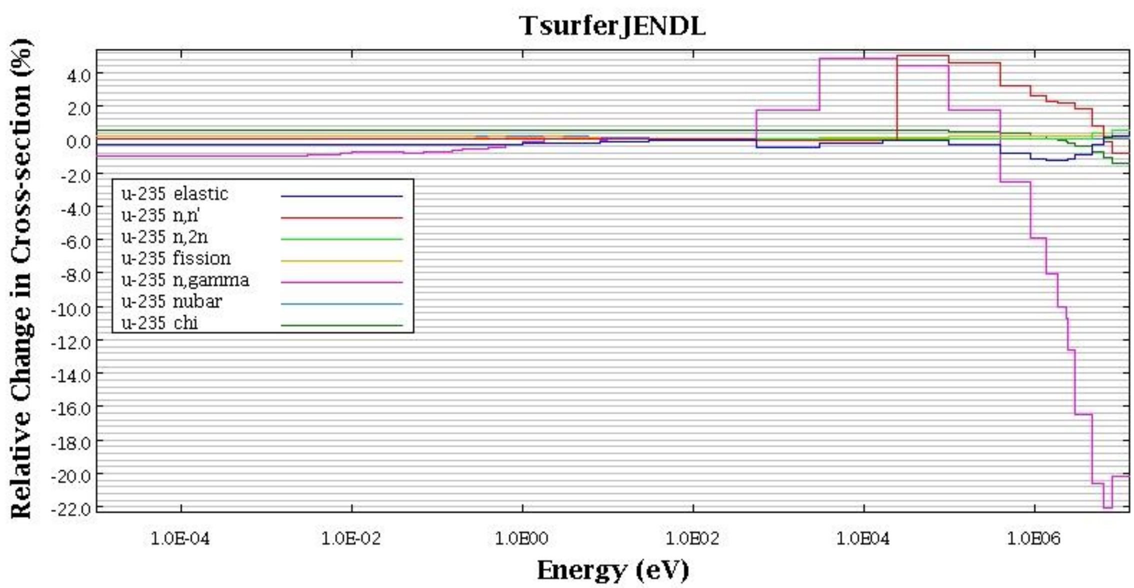

Figure 89) Cross Section Adjustment to ^{235}U for Molybdenum Cross Sections from JENDL4.0 with RPI resonance parameters

All of the modeled systems are by far most sensitive to the ^{235}U cross sections. Somewhat less dramatic adjustments are suggested for the ^{235}U cross sections when JENDL 4.0 and RPI cross-section data is used for the molybdenum isotopes, however the suggested adjustments to the ^{235}U capture cross section still dwarf all other adjustment suggested for the cross sections of other isotopes. Again, this is due to the high level of uncertainty of the ^{235}U capture cross section coupled with the high sensitivity of the system to that cross section.

Concluding Remarks

An improved set of high fidelity covariance data was developed for the natural isotopes of molybdenum. The series of proposed U-Moly fuel foil critical experiments were used as a basis to test the performance of the new molybdenum covariance data against the low fidelity set of molybdenum covariance data currently available. In order to isolate the effects of the new covariance data from the effect of the new molybdenum cross-section data, all permutations of old and new cross-section data and covariance data were explored. Significant improvements in bias reduction and slight improvement goodness-of-fit were observed when the new high fidelity covariance data and new molybdenum cross-section data were used in tandem.

Appendix D contains the RPI and JENDL 4.0 resolved resonance parameters, CVDH COV file 32 covariance, and CVDH COV file 33 covariance data for total, scattering, and capture reactions for the natural molybdenum isotopes.

Chapter 5: Conclusions

The primary objectives of this work were twofold: to demonstrate a novel means to generate a new high fidelity set of cross section covariance data for the natural molybdenum isotopes utilizing an elemental cross section evaluation, and design a series of molybdenum sensitive critical experiments that address deficiencies in the current critical experiment database with regards to the molybdenum isotopes. Both of these objectives were in support of the development of a new uranium molybdenum alloy fuel form for use in research and test reactors.

Incorporating data from multiple sources, a new high fidelity set of molybdenum isotope cross section covariance data was generated. The Bayesian analysis code SAMMY was used to generate uncertainty correlation data throughout the resolved resonance region for each of the molybdenum isotopes. This data was stored using the ENDF File 32 covariance data format. Additionally, integral uncertainty measurements, a dispersion method analysis, and high energy covariances generated at Brookhaven National Laboratory were incorporated to ensure the new covariance data satisfied the requirements set forth by the Cross Section Evaluation Working Group. This data was stored using the ENDF File 33 covariance data format.

A series of critical experiments was proposed to address deficiencies in molybdenum sensitivity in the currently available library of critical experiments. These critical experiments will feature the new intermediate enrichment U-Moly alloy fuel form, and will provide characterization of the fuel in both fast and thermal spectra. In particular, the thermal spectra critical experiments will be valuable, as there is a lack of U-Moly fueled critical experiments with a high thermal spectrum component.

Furthermore, the “Thermal Maximum Molybdenum Critical Experiment” will feature sensitivity to the molybdenum isotopes several orders of magnitude higher than any existing critical experiment, and should provide further insight into molybdenum isotope cross section uncertainty.

Finally, the newly generated high fidelity molybdenum covariance data library was used in a sensitivity and uncertainty study of the existing molybdenum sensitive critical experiments and the new proposed critical experiment series. When coupled with JENDL 4.0 cross section data, the high fidelity covariance data provided the best goodness-of-fit to the existing critical experiment data while simultaneously dramatically reducing the computational bias associated with the molybdenum isotopes as compared to the existing low fidelity covariance data.

The most immediate future work for this project would be the completion of the proposed critical experiments at the National Criticality Experiments Research Center. Completion of these critical experiments could serve as further validation of the high fidelity covariance library through more accurate and detailed computational modeling of the critical systems, and comparison of computational results to experimental results.

Secondly, while the resonance region uncertainty correlation produced for the new high fidelity covariance data was a significant improvement on the existing low fidelity library which assigns complete correlation throughout all energy regions, the correlation data could be improved further through the analysis of experimental molybdenum transmission and capture results for a larger segment of the resolved resonance region. The RPI experimental data extended to 2 keV for transmission measurements and to 600 eV for neutron capture measurements. This was sufficient to capture the effects of the large low lying resonances for all but one of the molybdenum isotopes, but to have complete knowledge of the correlation between the uncertainties for all of the resolved resonances experimental transmission and capture data throughout the entire resolved resonance region would be required. If this data was to become available, the program of work outlined in chapter 4 of this text could be repeated to produce a further improvement to the File 32 resonance-wise covariance data for the molybdenum isotopes.

Finally, while not directly within the scope of this project, the impact of high uncertainty in the ^{235}U capture cross section should be addressed, as it affects all attempts at the sort of sensitivity and uncertainty analysis possible through code packages such as TSUNAMI and TSURFER.

Appendices

Appendix A: Experimental Plans

The following were written in accordance with references [7], [11], and [12].

EXPERIMENTAL PLAN #1

STATIC CRITICAL EXPERIMENT FOR U(19.5%)-10Mo FUEL FOILS

OPERATIONAL LIMIT: Stage 1: multiplication ≤ 100.

Stage 2: delayed critical operation with positive periods ≥ 10 seconds.

ASSEMBLY MACHINE: Comet

REQUIRED PERSONELL: n/a

EXPECTED STARTING DATE: n/a

<u>Purpose</u>

To establish delayed critical conditions for U(19.5%)-10Mo fuel foils supplemented with HEU.

<u>Active Material</u>

Fuel will be 195 U(19.5%)-10Mo metal alloy foils with dimensions of 20" x 1.5" x 0.01". Additionally, 319.5 kg of HEU elements will be required to achieve criticality due to the intentional lack of moderation and resulting fast spectrum. Total uranium mass will be 334.17 kg, with 300.6 kg of ^{235}U.

<u>Assembly Description</u>

Two subcritical assemblies will be initially constructed by hand. Each of the subcritical assemblies will contain half of the U-Mo foils and HEU elements predicted for criticality. The U-Mo foils will be stacked closest to the centerline of the final experimental configuration, followed by the HEU elements. Two hand stacking rules will be observed during this phase. The first rule, the 75% rule, states that hand stacking will continue until the next additional fuel layer would exceed 75% of the extrapolated critical number of fuel foils. The second rule, the halfway rule, states that hand stacking can continue as long as the individual steps taken do not double the multiplication of the system or the count rate.

Once the two subcritical assembly halves have been completed, one will be placed on the top platform of the Comet machine, while the other will be placed on the lower movable platen of Comet. Comet will then be operated remotely observing the halfway rule described above.

Procedure

Stage 1: A neutron source will be located with the lower part of the critical assembly. BF3 counters placed around the assembly will monitor neutron multiplication. Neutron multiplication will be determined prior to experimentation from the same geometry, but without fuel material present. The lower part of the assembly will be remotely raised, following the halfway rule, and monitored by neutron multiplication. The lower platform will be raised incrementally to ascertain the behavior of the system until multiplication >100 is approached.

Stage 2: Following the successful completion of stage 1, a 1/M approach to critical procedure will be completed and a reactor period will be established. Reactivity effectiveness of various components will be measured, including fuel foils at multiple positions in the assembly.

Safety Precautions

Manual scram off the assembly will be available via the release of the movable platen of Comet. Computational modeling of the scram event indicates gravity driven drop of the lower platen represents an insertion of approximately -21500 pcm of reactivity. This will provide an adequate safety margin for the critical experiment. Additionally, all requirements of ANS N405 SAFETY GUIDE FOR THE PERFORMANCE OF CRITICAL EXPERIMENTS will be satisfied.

EXPERIMENTAL PLAN #2

STATIC CRITICAL EXPERIMENT FOR U(19.5%)-10Mo FUEL FOILS

OPERATIONAL LIMIT: Stage 1: multiplication ≤ 100.

Stage 2: delayed critical operation with positive periods ≥ 10 seconds.

ASSEMBLY MACHINE: Comet

REQUIRED PERSONELL: n/a

EXPECTED STARTING DATE: n/a

Purpose

To establish delayed critical conditions for U(19.5%)-10Mo fuel foils supplemented with HEU and reflected by graphite blocks.

Active Material

Fuel will be 195 U(19.5%)-10Mo metal alloy foils with dimensions of 20” x 1.5” x 0.01”. Additionally, 49.60 kg of HEU elements will be required to achieve criticality due to the intentional lack of moderation and resulting fast spectrum. Total uranium mass will be 64.27 kg, with 48.99 kg of ^{235}U.

Assembly Description

Two subcritical assemblies will be initially constructed by hand. Each of the subcritical assemblies will contain half of the U-Mo foils and HEU elements predicted for criticality. The U-Mo foils will be stacked closest to the centerline of the final experimental configuration, followed by the HEU elements. These fuel elements will be then surrounded by the graphite reflector elements. Two hand stacking rules will be observed during this phase. The first rule, the 75% rule, states that hand stacking will continue until the next additional fuel layer would exceed 75% of the extrapolated critical number of fuel foils. The second rule, the halfway rule, states that hand stacking can continue as long as the individual steps taken do not double the multiplication of the system or the count rate.

Once the two subcritical assembly halves have been completed, one will be placed on the top platform of the Comet machine, while the other will be placed on the lower movable platen of Comet. Comet will then be operated remotely observing the halfway rule described above.

Procedure

Stage 1: A neutron source will be located with the lower part of the critical assembly. BF3 counters placed around the assembly will monitor neutron multiplication. Neutron multiplication will be determined prior to experimentation from the same geometry, with the graphite reflector, but without fuel material present. The lower part of the assembly will be remotely raised, following the halfway rule, and monitored by neutron multiplication. The lower platform will be raised incrementally to ascertain the behavior of the system until multiplication >100 is approached.

Stage 2: Following the successful completion of stage 1, a 1/M approach to critical procedure will be completed and a reactor period will be established. Reactivity effectiveness of various components will be measured, including fuel foils at multiple positions in the assembly, as well as reflector and moderator layers.

Safety Precautions

Manual scram off the assembly will be available via the release of the movable platen of Comet. Computational modeling of the scram event indicates gravity driven drop of the lower platen represents an insertion of approximately -19500 pcm of reactivity. This will provide an adequate safety margin for the critical experiment.

Additionally, all requirements of ANS N405 SAFETY GUIDE FOR THE PERFORMANCE OF CRITICAL EXPERIMENTS will be satisfied.

EXPERIMENTAL PLAN #3

STATIC CRITICAL EXPERIMENT FOR U(19.5%)-10Mo FUEL FOILS

OPERATIONAL LIMIT: Stage 1: multiplication ≤ 100.

Stage 2: delayed critical operation with positive periods ≥ 10 seconds.

ASSEMBLY MACHINE: Comet

REQUIRED PERSONELL: n/a

EXPECTED STARTING DATE: n/a

Purpose

To establish delayed critical conditions for U(19.5%)-10Mo fuel foils moderated with Lucite and reflected by graphite blocks.

Active Material

Fuel will be 195 U(19.5%)-10Mo metal alloy foils with dimensions of 20” x 1.5” x 0.01”. Total uranium mass will be 14.67 kg, with 2.86 kg of ^{235}U.

Assembly Description

Assembly of the experimental setup will initially require hand stacking of alternating levels of Lucite plates and fuel foils. These layers will be stacked within a graphite reflector as calculated for the final critical state. Two hand stacking rules will be observed during this phase. The first rule, the 75% rule, states that hand stacking will continue until the next additional fuel layer would exceed 75% of the extrapolated critical number of fuel foils. The second rule, the halfway rule, states that hand stacking can continue as long as the individual steps taken do not double the multiplication of the system or the count rate. Assuming a linear relationship between multiplication and the number of foils in the assembly, if an addition step was to double the count rate, the next step of equal size would result in a system multiplication beyond delayed critical.

When the limit of one of the above hand stacking rules is reached, the assembly will be split into two parts. The bottom part containing approximately 80% of the fuel foils along with the neutron source is to be placed on the movable platen of Comet. The top part containing the remainder of the fuel foil and moderator layers will be placed on the top platform. Comet will then be operated remotely observing the halfway rule.

Procedure

Stage 1: A neutron source will be located with the lower part of the critical assembly. BF3 counters placed around the assembly will monitor neutron multiplication. Neutron multiplication will be determined prior to experimentation from the same geometry, with graphite reflector and Lucite moderator in place, but without fuel foils present. The lower part of the assembly will be remotely raised, following the halfway rule, and monitored by neutron multiplication. The lower platform will be raised incrementally to ascertain the behavior of the system until multiplication >100 is approached.

Stage 2: Following the successful completion of stage 1, a 1/M approach to critical procedure will be completed and a reactor period will be established. Reactivity effectiveness of various components will be measured, including fuel foils at multiple positions in the assembly, as well as reflector and moderator layers.

Safety Precautions

Manual scram off the assembly will be available via the release of the movable platen of Comet. Computational modeling of the scram event indicates gravity driven drop of the lower platen represents an insertion of approximately -3500 pcm of reactivity. This will provide an adequate safety margin for the critical experiment. Additionally, all requirements of ANS N405 SAFETY GUIDE FOR THE PERFORMANCE OF CRITICAL EXPERIMENTS will be satisfied.

EXPERIMENTAL PLAN #4

STATIC CRITICAL EXPERIMENT FOR U(19.5%)-10Mo FUEL FOILS

OPERATIONAL LIMIT: Stage 1: multiplication ≤ 100.

Stage 2: delayed critical operation with positive periods ≥ 10 seconds.

ASSEMBLY MACHINE: Comet

REQUIRED PERSONELL: n/a

EXPECTED STARTING DATE: n/a

Purpose

To establish delayed critical conditions for U(19.5%)-10Mo fuel foils moderated with Lucite and molybdenum metal and reflected by graphite blocks.

Active Material

Fuel will be 195 U(19.5%)-10Mo metal alloy foils with dimensions of 20" x 1.5" x 0.01". Total uranium mass will be 14.67 kg, with 2.86 kg of ^{235}U.

Assembly Description

Assembly of the experimental setup will initially require hand stacking of alternating levels of Lucite plates, molybdenum metal plates, and fuel foils. These layers will be stacked within a graphite reflector as calculated for the final critical state. Two hand stacking rules will be observed during this phase. The first rule, the 75% rule, states that hand stacking will continue until the next additional fuel layer would exceed 75% of the extrapolated critical number of fuel foils. The second rule, the halfway rule, states that hand stacking can continue as long as the individual steps taken do not double the multiplication of the system or the count rate. Assuming a linear relationship between multiplication and the number of foils in the assembly, if an addition step was to double the count rate, the next step of equal size would result in a system multiplication beyond delayed critical.

When the limit of one of the above hand stacking rules is reached, the assembly will be split into two parts. The bottom part containing approximately 80% of the fuel foils along with the neutron source is to be placed on the movable platen of Comet. The top part containing the remainder of the fuel foil and moderator layers will be placed on the top platform. Comet will then be operated remotely observing the halfway rule.

Procedure

Stage 1: A neutron source will be located with the lower part of the critical assembly. BF3 counters placed around the assembly will monitor neutron multiplication. Neutron multiplication will be determined prior to experimentation from the same geometry, with graphite reflector, Lucite moderator, and molybdenum metal moderator in place, but without fuel foils present. The lower part of the assembly will be remotely raised, following the halfway rule, and monitored by neutron multiplication. The lower platform will be raised incrementally to ascertain the behavior of the system until multiplication >100 is approached.

Stage 2: Following the successful completion of stage 1, a 1/M approach to critical procedure will be completed and a reactor period will be established. Reactivity effectiveness of various components will be measured, including fuel foils at multiple positions in the assembly, as well as reflector and moderator layers.

Safety Precautions

Manual scram off the assembly will be available via the release of the movable platen of Comet. Computational modeling of the scram event indicates gravity driven drop of the lower platen represents an insertion of approximately -3800 pcm of reactivity. This will provide an adequate safety margin for the critical experiment. Additionally, all requirements of ANS N405 SAFETY GUIDE FOR THE PERFORMANCE OF CRITICAL EXPERIMENTS will be satisfied.

Appendix B: MCNP Materials and Inputs

Material compositions were derived as follows from references [13] and [14].

U(19.5%)-10Mo

Density: 15.3 g/cm^3

Atom fraction:

^{235}U	0.158805
^{238}U	0.625053
^{92}Mo	0.032075
^{94}Mo	0.019993
^{95}Mo	0.03441
^{96}Mo	0.036052
^{97}Mo	0.020641
^{98}Mo	0.052155
^{100}Mo	0.020814

Lucite

Density: 1.19 g/cm^3

Atom Fraction:

H	0.533320
C	0.333345
O	0.133335

HEU

Density: 18.95 g/cm^3

Atom Fraction:

^{234}U	0.009849
^{235}U	0.932166
^{236}U	0.004484
^{238}U	0.053501

Graphite

Density: 1.70 g/cm^3

Atom Fraction:

C	1.0

Molybdenum Metal

Density: 10.28 g/cm^3

Atom Fraction:

^{92}Mo	0.1484
^{94}Mo	0.0925
^{95}Mo	0.1592
^{96}Mo	0.1668
^{97}Mo	0.0955
^{98}Mo	0.2413
^{100}Mo	0.0963

Fast Bare Critical Experiment Design

```
Fast Critical Experiment U(19.5%)-10Mo and HEU
C
C 10" x 9" x Z pile of U-Mo and plexiglass
C
C Cell Cards
1 1  0.049079 -1 imp:n=1  $U-Mo
2 3  -18.95 -2 imp:n=1 $HEU
3 3  -18.95 -3 imp:n=1 $HEU
4 4  0.001205 -5 #1 #2 #3 imp:n=1 $Reflector
5 0 5 imp:n=0 $Exterior

C Surface Cards
C Fuel Region Surfaces
1 rpp -25.4 25.4 -24.765 24.765 -1.905 1.905
2 rpp -25.4 25.4 -24.765 24.765 1.905 5.255
3 rpp -25.4 25.4 -24.765 24.765 -5.255 -1.905
5 rpp -50 50 -50 50 -10 10

C Data Cards
kcode 10000 1.0 50 500
ksrc 0.0 0.0 0.0
C Material Cards
   m1  92235 0.007794
       92238 0.030677
       42092.52c 0.001574227
       42094.52c 0.00098124
       42095.52c 0.001688794
       42096.52c 0.001769414
       42097.52c 0.001013064
       42098.52c 0.00255971
       42100.52c 0.00102155
   m3  92234 0.009849
       92235 0.932166
       92236 0.004484
       92238 0.053501
   m4  6000 0.000151 $ C
       7014 0.784437 $ N
       8016 0.210750 $ O
       18000 0.004671 $ Ar
```

Fast Reflected Critical Experiment Design

```
Fast Critical Experiment U(19.5%)-10Mo and HEU. Graphite
reflected.
C
C 10" x 9" x Z pile of U-Mo and HEU
C
C Cell Cards
1 1  0.049079 -1 imp:n=1  $U-Mo
2 3  -18.95 -2 imp:n=1 $HEU
3 3  -18.95 -3 imp:n=1 $HEU
4 2  8.523800E-02 -5 #1 #2 #3 imp:n=1 $Reflector
5 0 5 imp:n=0 $Exterior

C Surface Cards
C Fuel Region Surfaces
1 rpp -25.4 25.4 -24.765 24.765 -1.905 1.905
2 rpp -25.4 25.4 -24.765 24.765 1.905 2.425
3 rpp -25.4 25.4 -24.765 24.765 -2.425 -1.905
5 rpp -50 50 -50 50 -27.425 -27.425

C Data Cards
kcode 10000 1.0 50 500
ksrc 0.0 0.0 0.0
C Material Cards
   m1  92235 0.007794
       92238 0.030677
       42092 0.001574227
       42094 0.00098124
       42095 0.001688794
       42096 0.001769414
       42097 0.001013064
       42098 0.00255971
       42100 0.00102155
   m2  6012 1
   m3  92234 0.009849
       92235 0.932166
       92236 0.004484
       92238 0.053501
```

Thermal Standard Molybdenum Critical Experiment Design

```
Critical Experiment U-Mo and Lucite
C
C 10" x 9" x Z pile of U-Mo and plexiglass reflected with
graphite
C
C Cell Cards
C Fuel Foils
1 2  0.049079 -1 -3 4 imp:n=1
2 2  0.049079 -1 -5 6 imp:n=1
3 2  0.049079 -1 -7 8 imp:n=1
4 2  0.049079 -1 -9 10 imp:n=1
5 2  0.049079 -1 -11 12 imp:n=1
6 2  0.049079 -1 -13 14 imp:n=1
7 2  0.049079 -1 -15 16 imp:n=1
8 2  0.049079 -1 -17 18 imp:n=1
9 2  0.049079 -1 -19 20 imp:n=1
10 2  0.049079 -1 -21 22 imp:n=1
11 2  0.049079 -1 -23 24 imp:n=1
12 2  0.049079 -1 -25 26 imp:n=1
13 2  0.049079 -1 -27 28 imp:n=1
14 2  0.049079 -1 -29 30 imp:n=1
15 2  0.049079 -1 -31 32 imp:n=1
C Moderator Plates
20 1 0.107369 -1 -2 3 imp:n=1
21 1 0.107369 -1 -4 5 imp:n=1
22 1 0.107369 -1 -6 7 imp:n=1
23 1 0.107369 -1 -8 9 imp:n=1
24 1 0.107369 -1 -10 11 imp:n=1
25 1 0.107369 -1 -12 13 imp:n=1
26 1 0.107369 -1 -14 15 imp:n=1
27 1 0.107369 -1 -16 17 imp:n=1
28 1 0.107369 -1 -18 19 imp:n=1
29 1 0.107369 -1 -20 21 imp:n=1
30 1 0.107369 -1 -22 23 imp:n=1
31 1 0.107369 -1 -24 25 imp:n=1
32 1 0.107369 -1 -26 27 imp:n=1
33 1 0.107369 -1 -28 29 imp:n=1
34 1 0.107369 -1 -30 31 imp:n=1
35 1 0.107369 -1 -32 33 imp:n=1
C Graphite Reflector
50 3  8.523800E-02 -50 1 imp:n=1
100 0 50 imp:n=0 $Exterior

C Surface Cards
C Fuel Region Surfaces
1 rpp -25.4 25.4 -24.765 24.765 -26.65397 26.65397
```

```
2 pz 26.65397
3 pz 23.34603
4 pz 23.32063
5 pz 20.01270
6 pz 19.98730
7 pz 16.67937
8 pz 16.65397
9 pz 13.34603
10 pz 13.32063
11 pz 10.01270
12 pz 9.98730
13 pz 6.67937
14 pz 6.65397
15 pz 3.34603
16 pz 3.32063
17 pz 0.01270
18 pz -0.01270
19 pz -3.32063
20 pz -3.34603
21 pz -6.65397
22 pz -6.67937
23 pz -9.98730
24 pz -10.01270
25 pz -13.32063
26 pz -13.34603
27 pz -16.65397
28 pz -16.67937
29 pz -19.98730
30 pz -20.01270
31 pz -23.32063
32 pz -23.34603
33 pz -26.65397
C Reflector Region Surface
50 rpp -50 50 -50 50 -50 50

C Data Cards
kcode 10000 1.0 50 500
ksrc 0 0 0
C Material Cards
   m1  1001 0.057262
       6012 0.035791
       8016 0.014316
   mt1 poly.11t
   m2  92235 0.007794
       92238 0.030677
       42092 0.001574227
       42094 0.00098124
       42095 0.001688794
```

```
    42096 0.001769414
    42097 0.001013064
    42098 0.00255971
    42100 0.00102155
m3  6012 1
```

Thermal Maximum Molybdenum Critical Experiment Design

```
C Critical Experiment U-Mo, Molybdenum Metal, and Lucite.
Graphite
C Reflector
C 10" x 9" x Z pile of U-Mo and plexiglass
C
C Cell Cards
C Fuel Foils
1 2  0.049079 -1 -4 5 imp:n=1
2 2  0.049079 -1 -7 8 imp:n=1
3 2  0.049079 -1 -10 11 imp:n=1
4 2  0.049079 -1 -13 14 imp:n=1
5 2  0.049079 -1 -16 17 imp:n=1
6 2  0.049079 -1 -19 20 imp:n=1
7 2  0.049079 -1 -22 23 imp:n=1
8 2  0.049079 -1 -25 26 imp:n=1
9 2  0.049079 -1 -28 29 imp:n=1
10 2  0.049079 -1 -31 32 imp:n=1
11 2  0.049079 -1 -34 35 imp:n=1
12 2  0.049079 -1 -37 38 imp:n=1
13 2  0.049079 -1 -40 41 imp:n=1
14 2  0.049079 -1 -43 44 imp:n=1
15 2  0.049079 -1 -46 47 imp:n=1
C Lucite Moderator Plates
20 1 0.107369 -1 -2 3 imp:n=1
21 1 0.107369 -1 -5 6 imp:n=1
22 1 0.107369 -1 -8 9 imp:n=1
23 1 0.107369 -1 -11 12 imp:n=1
24 1 0.107369 -1 -14 15 imp:n=1
25 1 0.107369 -1 -17 18 imp:n=1
26 1 0.107369 -1 -20 21 imp:n=1
27 1 0.107369 -1 -23 24 imp:n=1
28 1 0.107369 -1 -27 28 imp:n=1
29 1 0.107369 -1 -30 31 imp:n=1
30 1 0.107369 -1 -33 34 imp:n=1
31 1 0.107369 -1 -36 37 imp:n=1
32 1 0.107369 -1 -39 40 imp:n=1
33 1 0.107369 -1 -42 43 imp:n=1
34 1 0.107369 -1 -45 46 imp:n=1
35 1 0.107369 -1 -48 49 imp:n=1
C Molybdenum Metal Layers
40 4 -10.28 -1 -3 4 imp:n=1
41 4 -10.28 -1 -6 7 imp:n=1
42 4 -10.28 -1 -9 10 imp:n=1
43 4 -10.28 -1 -12 13 imp:n=1
```

```
44 4 -10.28 -1 -15 16 imp:n=1
45 4 -10.28 -1 -18 19 imp:n=1
46 4 -10.28 -1 -21 22 imp:n=1
47 4 -10.28 -1 -24 25 imp:n=1
48 4 -10.28 -1 -26 27 imp:n=1
49 4 -10.28 -1 -29 30 imp:n=1
50 4 -10.28 -1 -32 33 imp:n=1
51 4 -10.28 -1 -35 36 imp:n=1
52 4 -10.28 -1 -38 39 imp:n=1
53 4 -10.28 -1 -41 42 imp:n=1
54 4 -10.28 -1 -44 45 imp:n=1
55 4 -10.28 -1 -47 48 imp:n=1
C Graphite Reflector
60 3  8.523800E-02 -50 1 imp:n=1
100 0 50 imp:n=0 $Exterior

C Surface Cards
C Fuel Region Surfaces
1 rpp -25.4 25.4 -24.765 24.765 -14.20970 14.20970
2     pz   14.20970      $Top of Moderator
3     pz   12.60970      $Top of Moly
4     pz   12.45730      $Top of Fuel
5     pz   12.43190      $Top of Moderator
6     pz   10.83190      $Top of Moly
7     pz   10.67950      $Top of Fuel
8     pz   10.65410      $Top of Moderator
9     pz   9.05410       $Top of Moly
10    pz   8.90170       $Top of Fuel
11    pz   8.87630       $Top of Moderator
12    pz   7.27630       $Top of Moly
13    pz   7.12390       $Top of Fuel
14    pz   7.09850       $Top of Moderator
15    pz   5.49850       $Top of Moly
16    pz   5.34610       $Top of Fuel
17    pz   5.32070       $Top of Moderator
18    pz   3.72070       $Top of Moly
19    pz   3.56830       $Top of Fuel
20    pz   3.54290       $Top of Moderator
21    pz   1.94290       $Top of Moly
22    pz   1.79050       $Top of Fuel
23    pz   1.76510       $Top of Moderator
24    pz   0.16510       $Top of Moly
25    pz   0.01270       $Top of Fuel
26    pz   -0.01270      $Top of Moly
27    pz   -0.16510      $Top of Moderator
28    pz   -1.76510      $Top of Fuel
29    pz   -1.79050      $Top of Moly
30    pz   -1.94290      $Top of Moderator
```

```
31    pz    -3.54290       $Top of Fuel
32    pz    -3.56830       $Top of Moly
33    pz    -3.72070       $Top of Moderator
34    pz    -5.32070       $Top of Fuel
35    pz    -5.34610       $Top of Moly
36    pz    -5.49850       $Top of Moderator
37    pz    -7.09850       $Top of Fuel
38    pz    -7.12390       $Top of Moly
39    pz    -7.27630       $Top of Moderator
40    pz    -8.87630       $Top of Fuel
41    pz    -8.90170       $Top of Moly
42    pz    -9.05410       $Top of Moderator
43    pz    -10.65410      $Top of Fuel
44    pz    -10.67950      $Top of Moly
45    pz    -10.83190      $Top of Moderator
46    pz    -12.43190      $Top of Fuel
47    pz    -12.45730      $Top of Moly
48    pz    -12.60970      $Top of Moderator
49    pz    -14.20970      $Bottom of Moderator
C Reflector Region Surface
50 rpp -75 75 -75 75 -75 75

C Data Cards
kcode 2000 1.0 20 200
ksrc 0 0 0
C Material Cards
   m1  1001 0.057262
       6012 0.035791
       8016 0.014316
   mt1 poly.11t
   m2  92235 0.007794
       92238 0.030677
       42092.50c 0.001574227
       42094.50c 0.00098124
       42095.50c 0.001688794
       42096.50c 0.001769414
       42097.50c 0.001013064
       42098.50c 0.00255971
       42100.50c 0.00102155
   m3  6012 1
   mt3 grph.10t
   m4  42092.50c 0.1484
       42094.50c 0.0925
       42095.50c 0.1592
       42096.50c 0.1668
       42097.50c 0.0955
       42098.50c 0.2413
       42100.50c 0.0963
```

Appendix C: File 32 and File 33 Covariance Plots

^{92}Mo

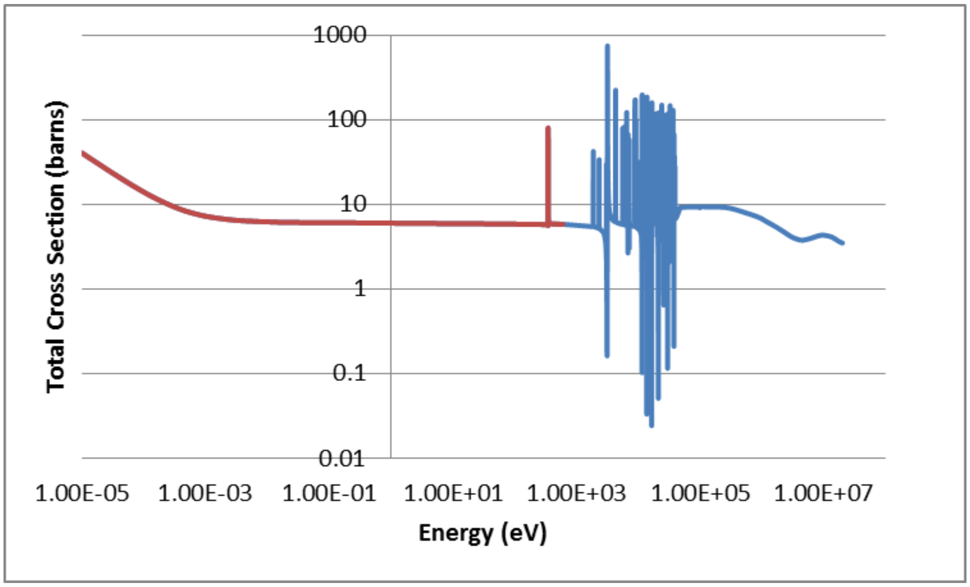

Figure C.1) ENDF/B-VII.1 ^{92}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

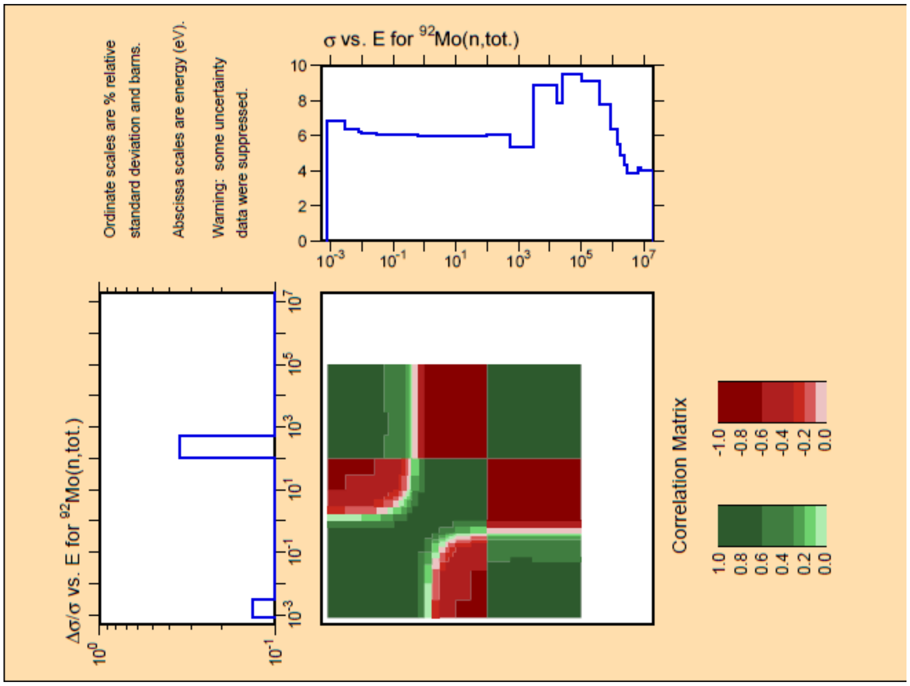

Figure C.2) ^{92}Mo Total File 32 Covariance

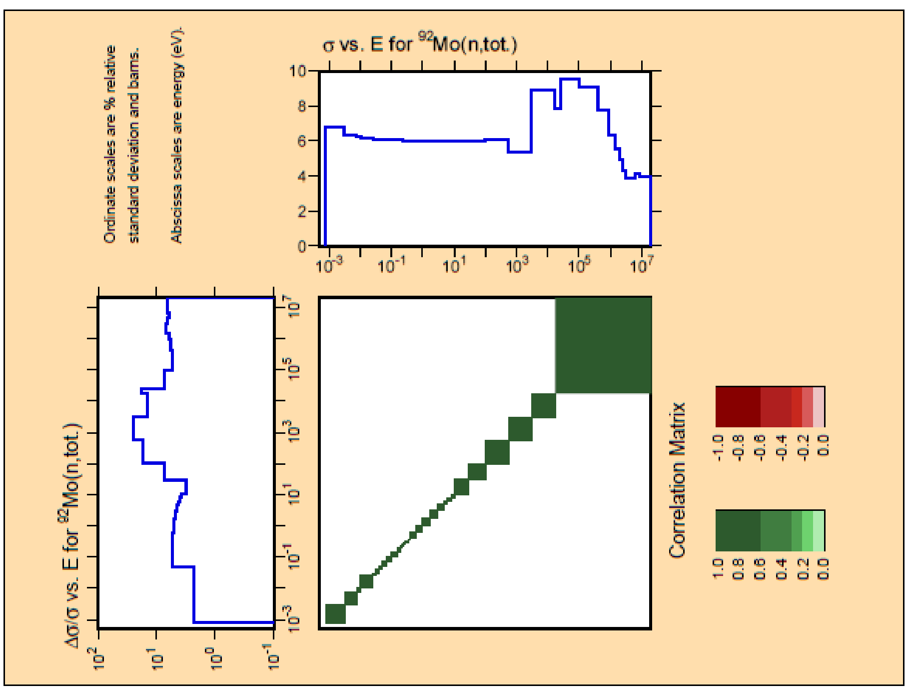

Figure C.3) ^{92}Mo Total File 33 Covariance

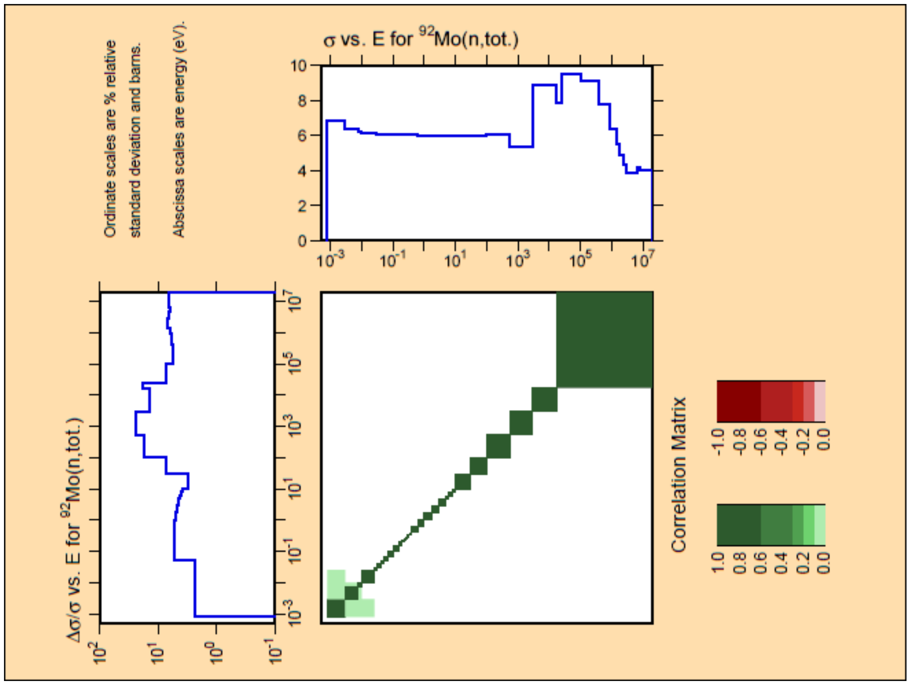

Figure C.4) ^{92}Mo CVDHCOV Total Covariance Data

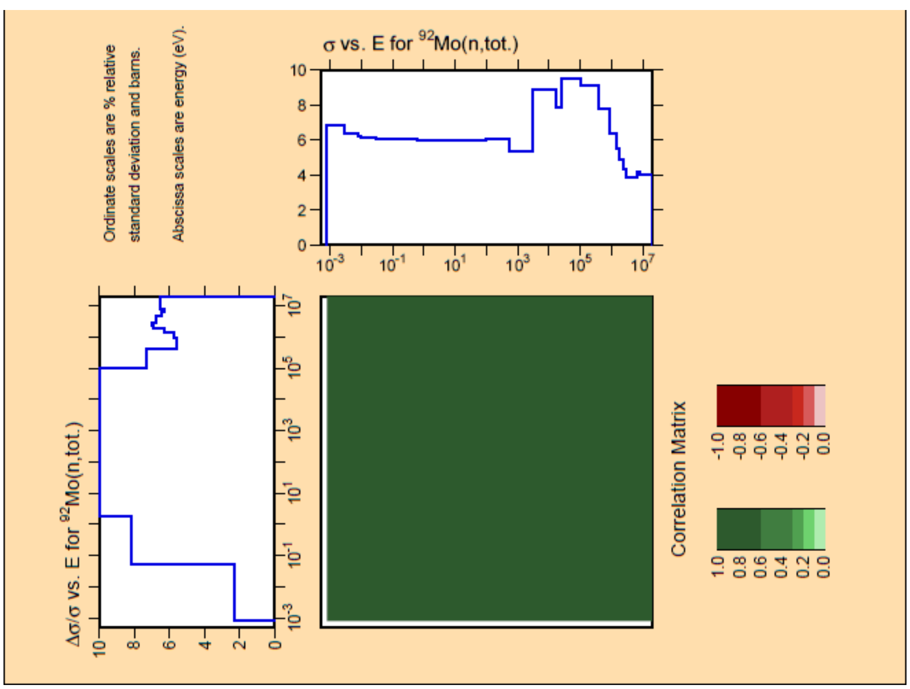

Figure C.5) ^{92}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

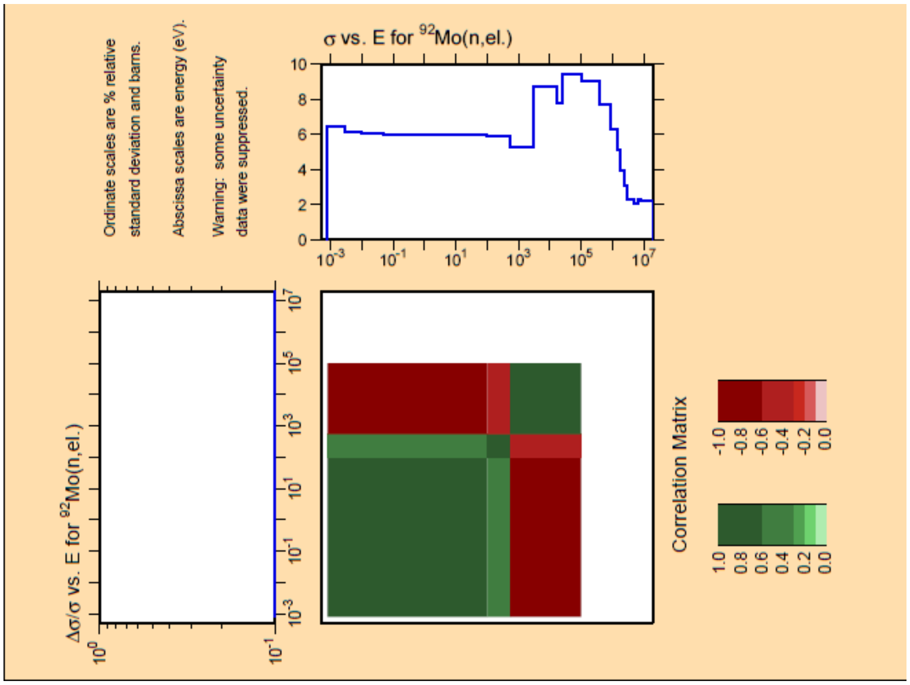

Figure C.6) ^{92}Mo Elastic Scattering File 32 Covariance

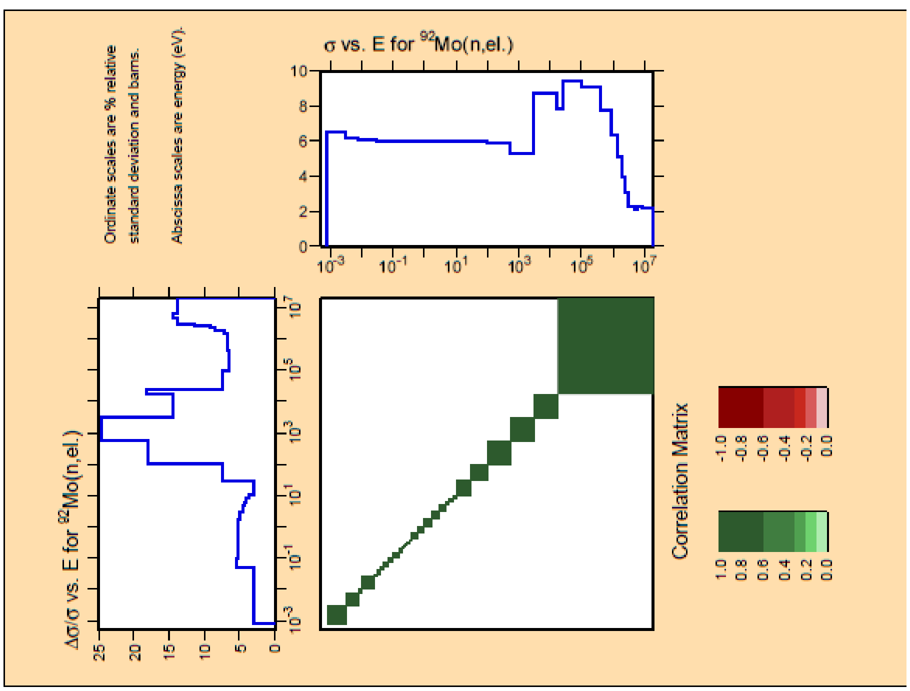

Figure C.7) ^{92}Mo Elastic Scattering File 33 Covariance

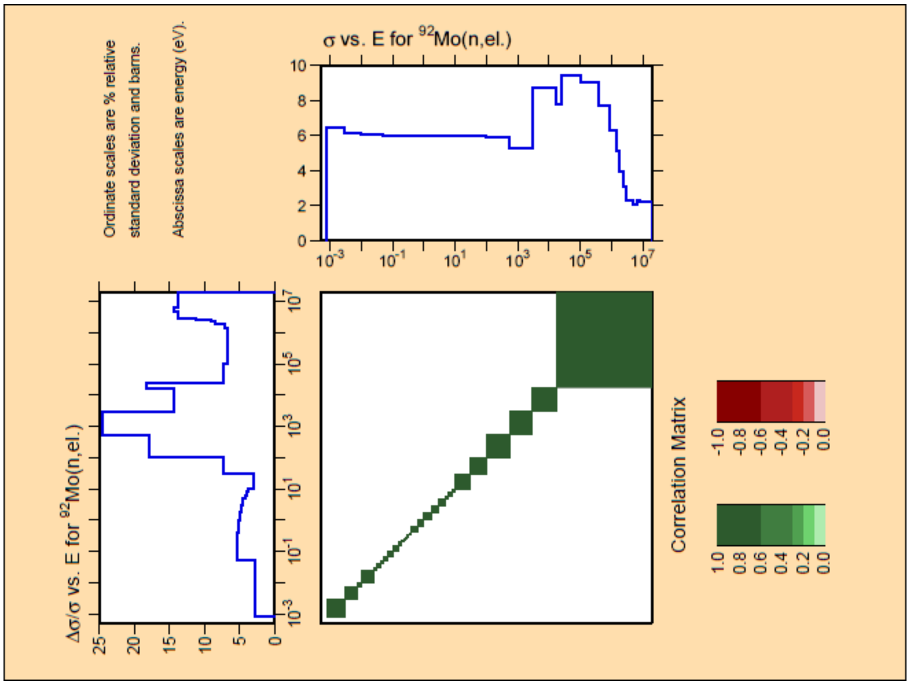

Figure C.8) ^{92}Mo CVDHCOV Elastic Scattering Covariance Data

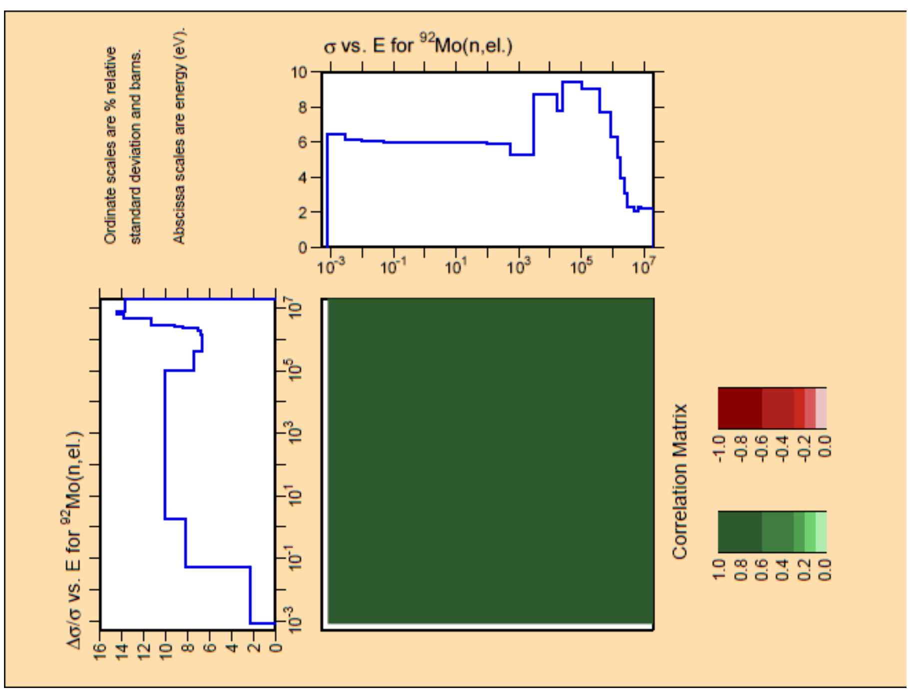

Figure C.9) ^{92}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

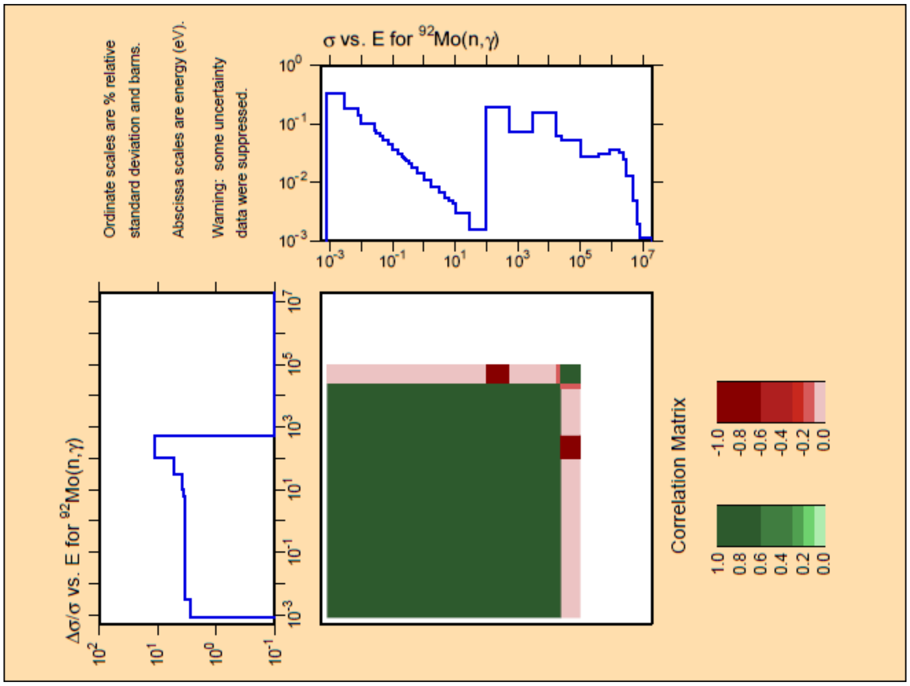

Figure C.10) ^{92}Mo Capture File 32 Covariance

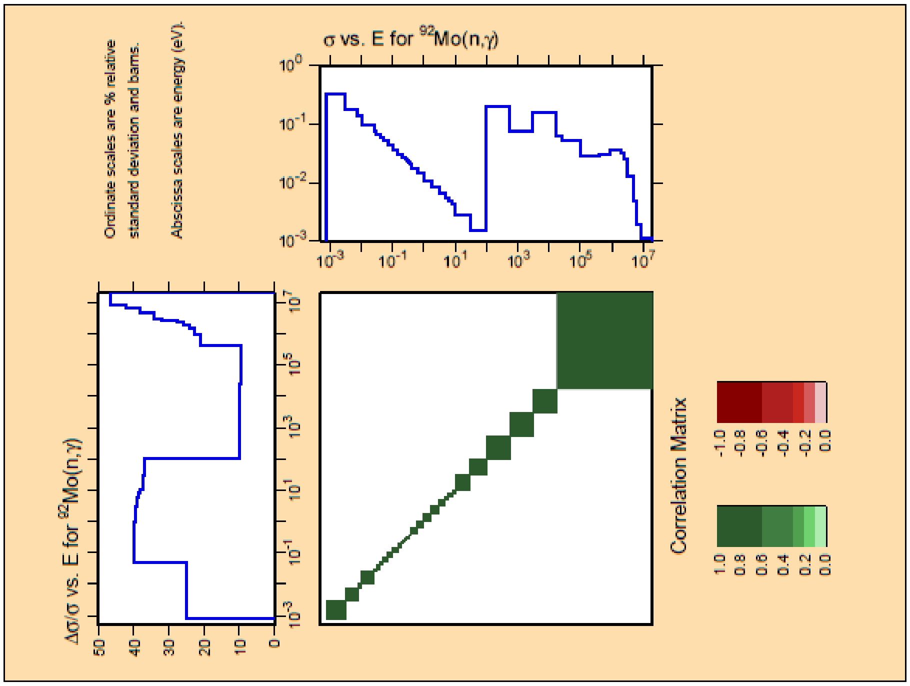

Figure C.11) ^{92}Mo Capture File 33 Covariance

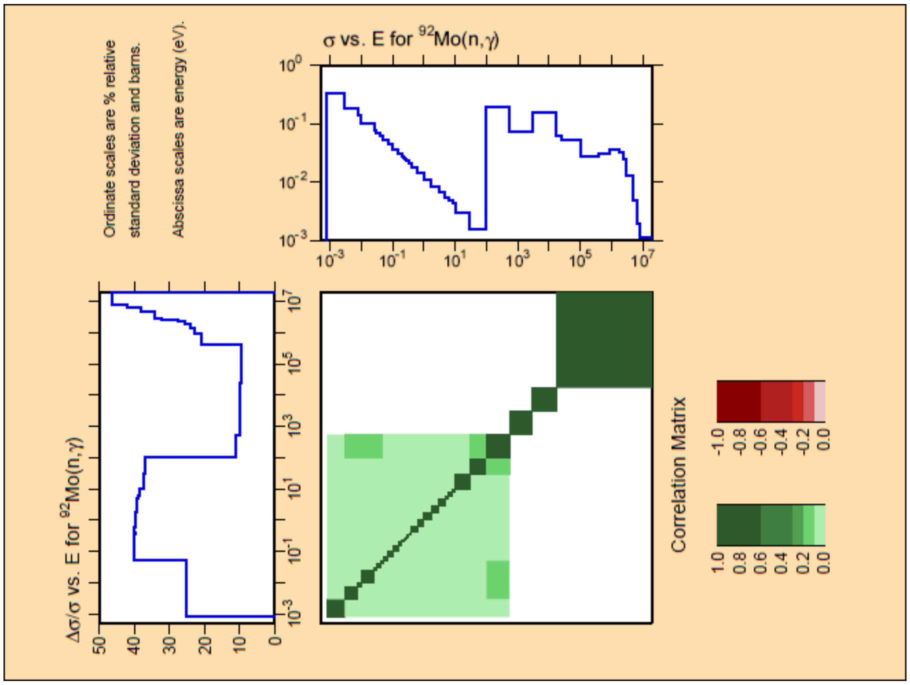

Figure C.12) ^{92}Mo CVDHCOV Capture Covariance Data

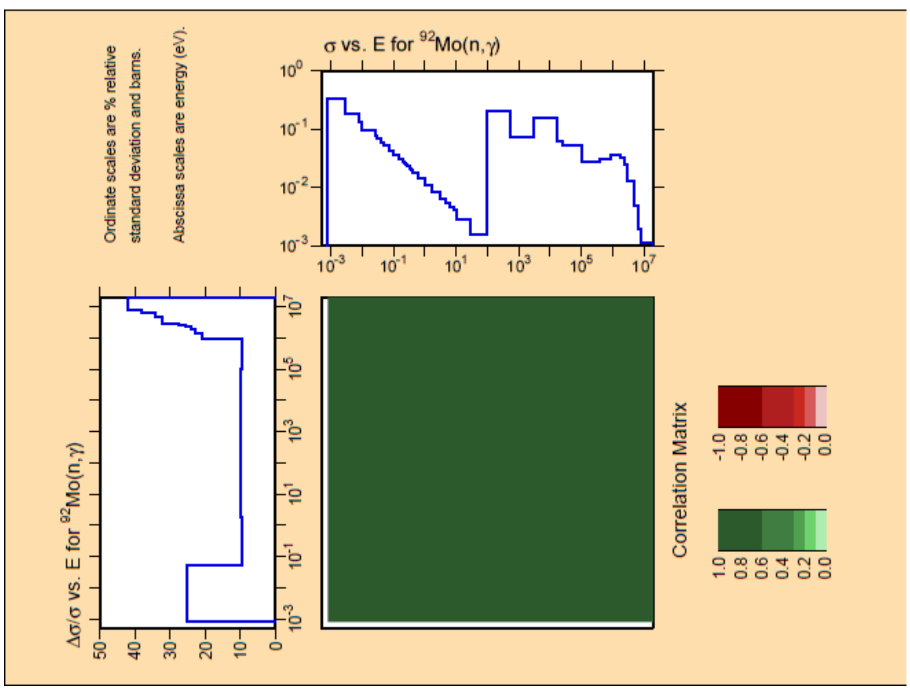

Figure C.13) ^{92}Mo LOFI Capture Covariance Data

^{94}Mo

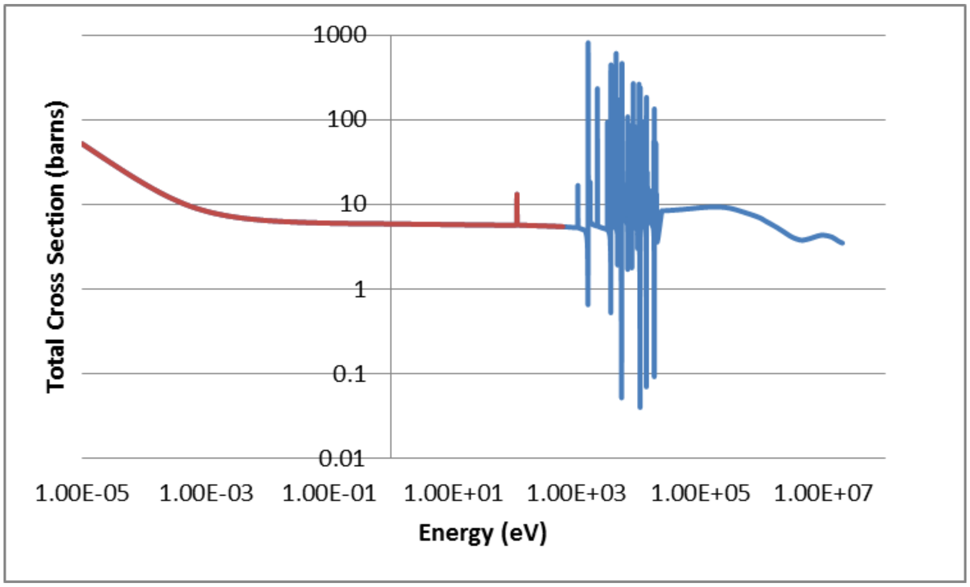

Figure C.14) ENDF/B-VII.1 94Mo Total Cross Section, 0-600 eV highlighted

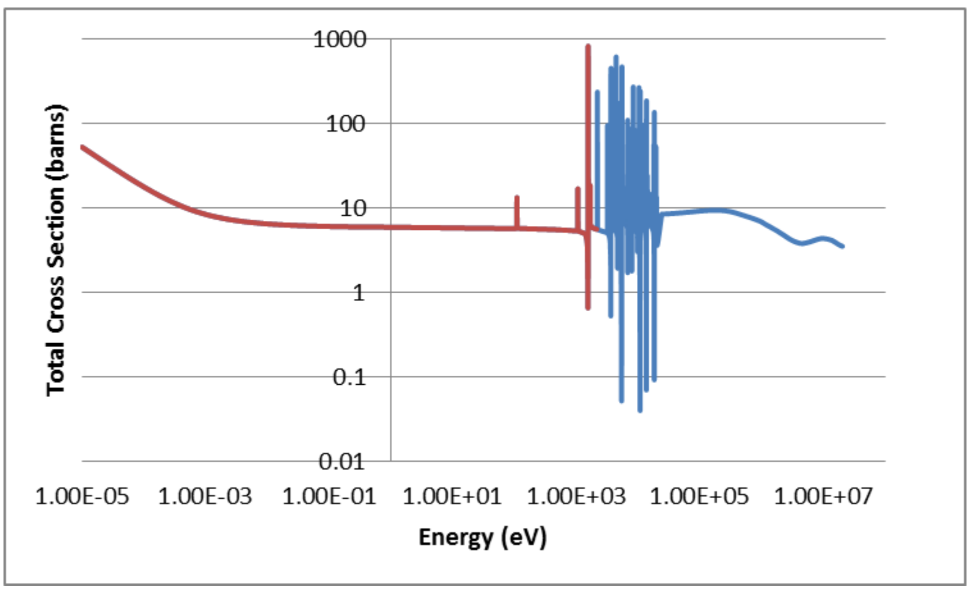

Figure C.15) ENDF/B-VII.1 ^{94}Mo Total Cross Section, 0-2000 eV highlighted

Total Covariance Data

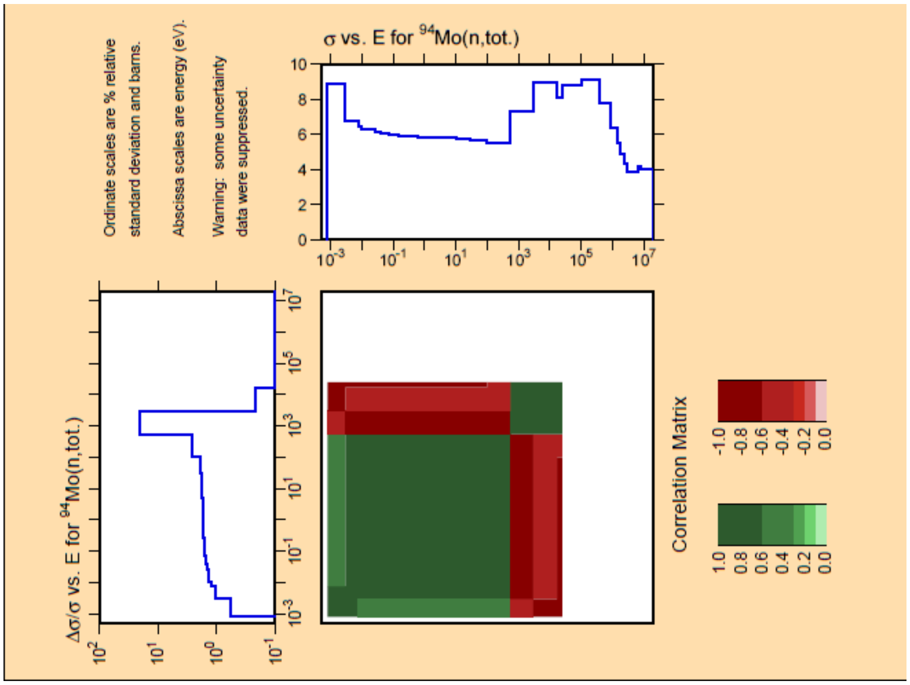

Figure C.16) ^{94}Mo Total File 32 Covariance Data

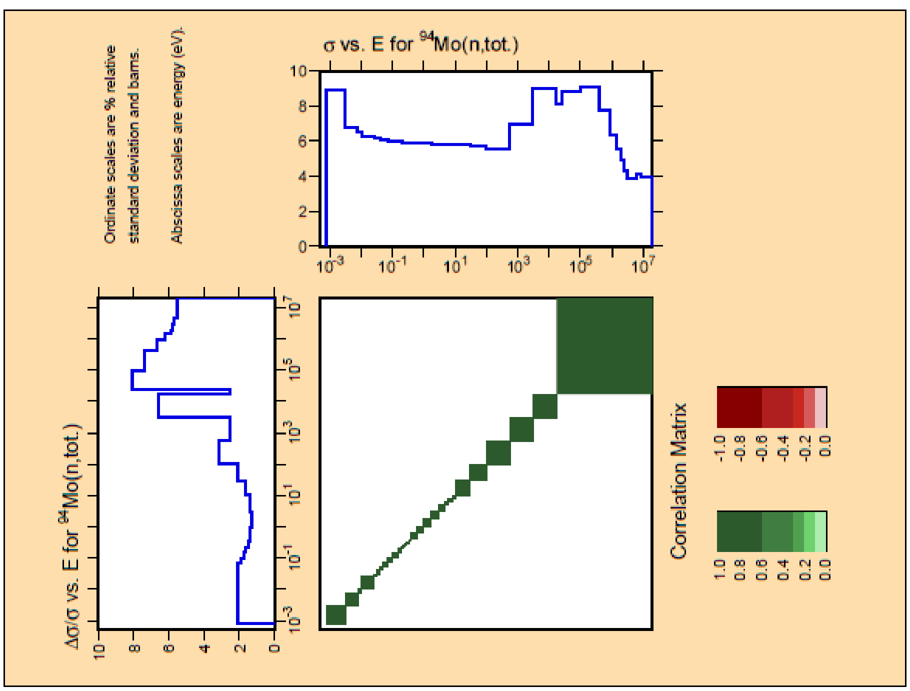

Figure C.17) ^{94}Mo Total File 33 Covariance Data

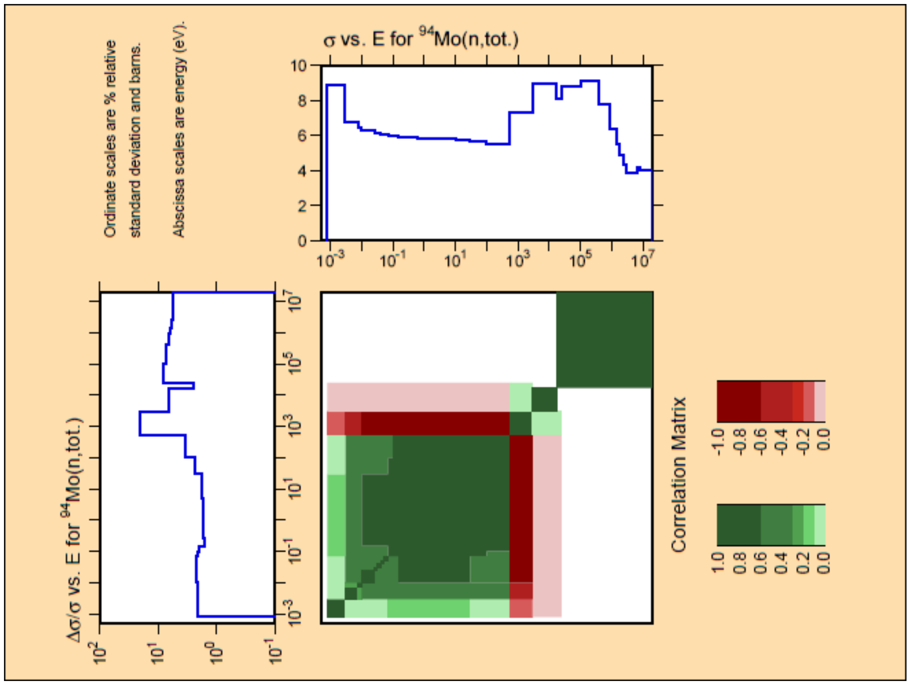

Figure C.18) ^{94Mo} CVDHCOV Total Covariance Data

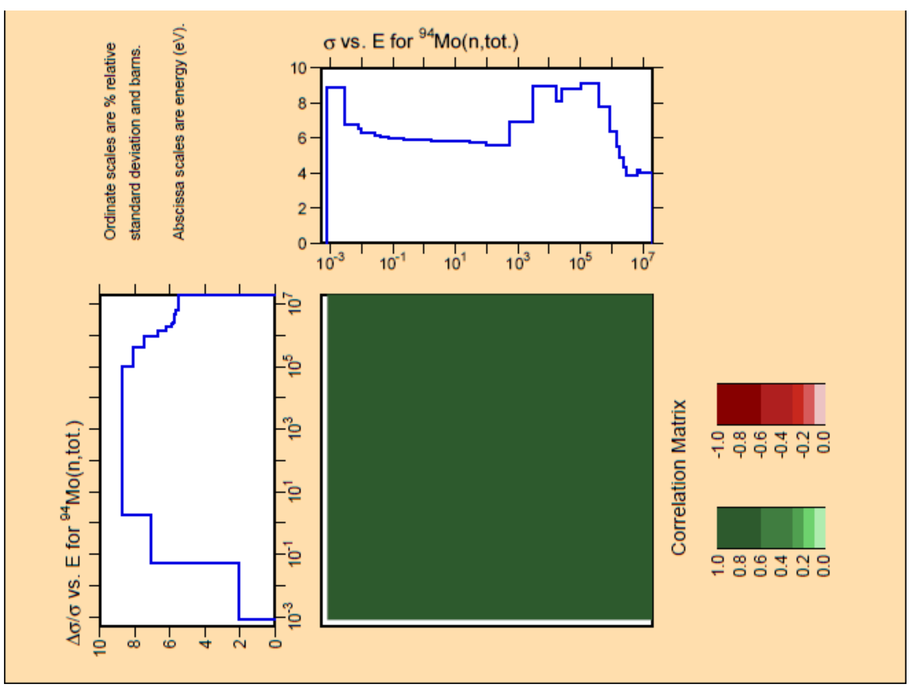

Figure C.19) ^{94}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

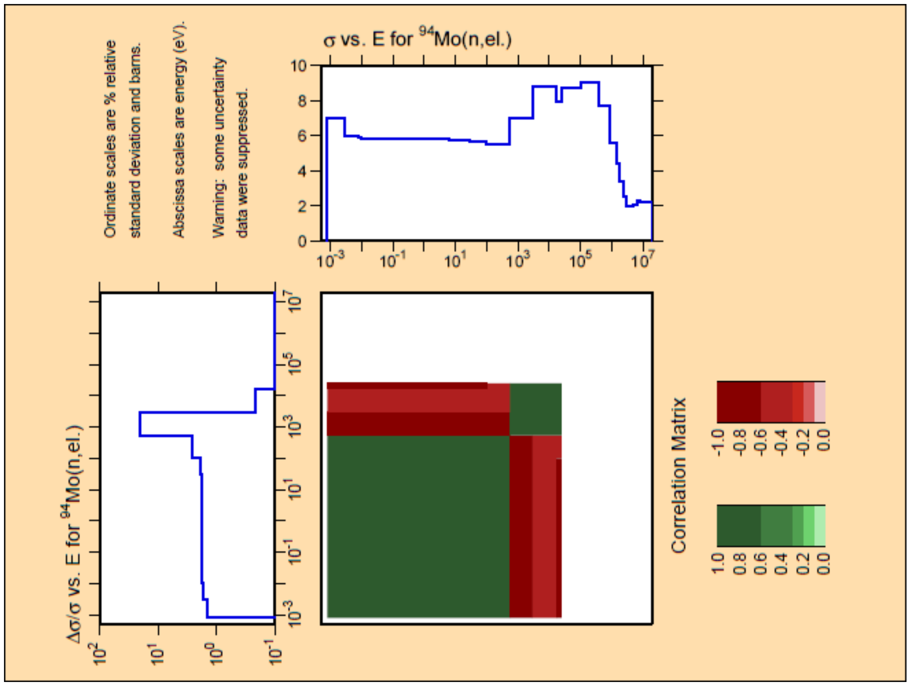

Figure C.20) ^{94}Mo Elastic Scattering File 32 Covariance Data

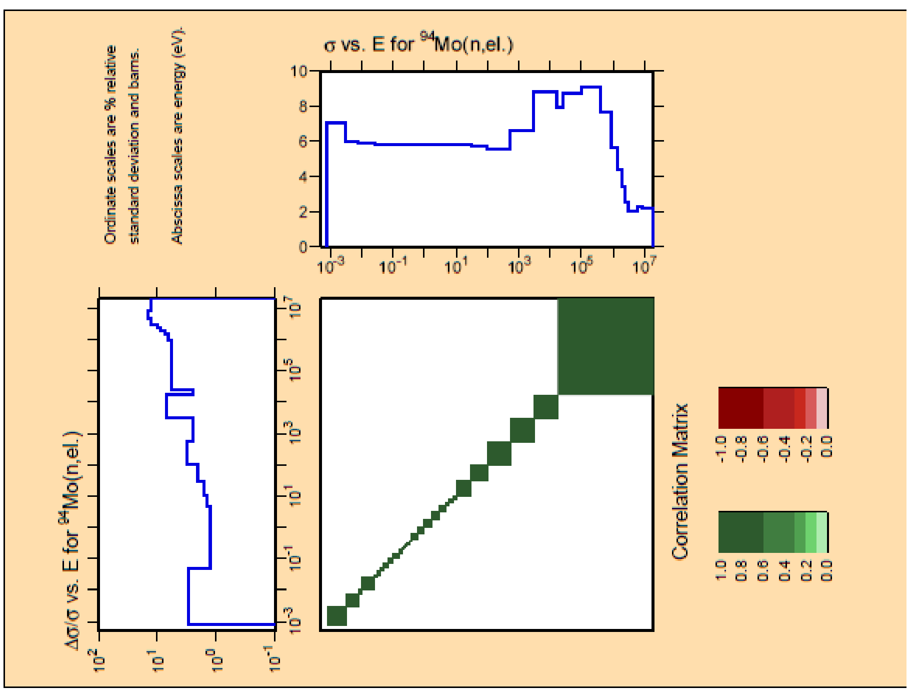

Figure C.21) ^{94}Mo Elastic Scattering File 33 Covariance Data

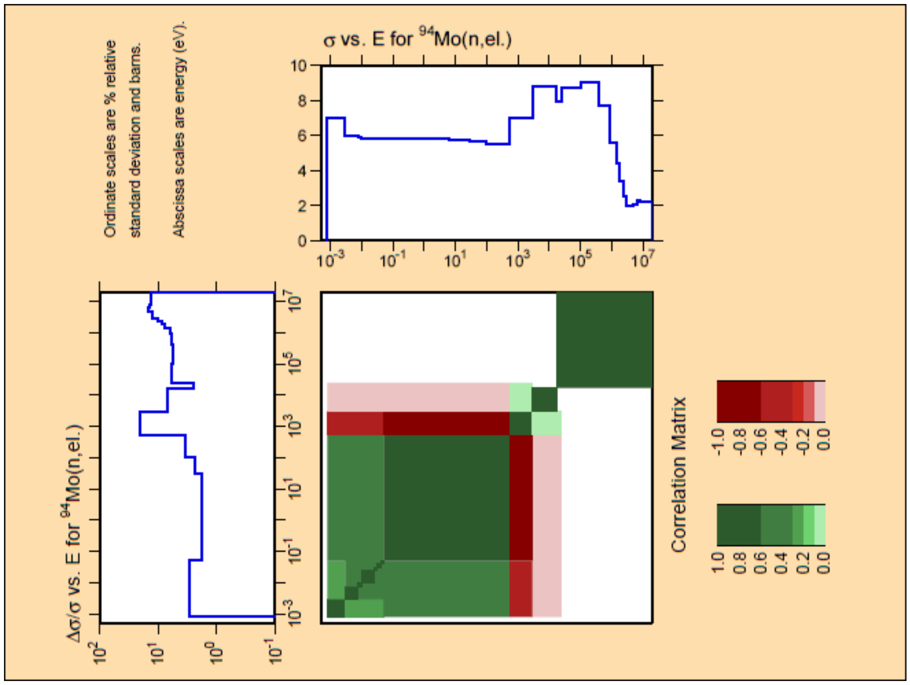

Figure C.22) ^{94}Mo CVDHCOV Elastic Scattering Covariance Data

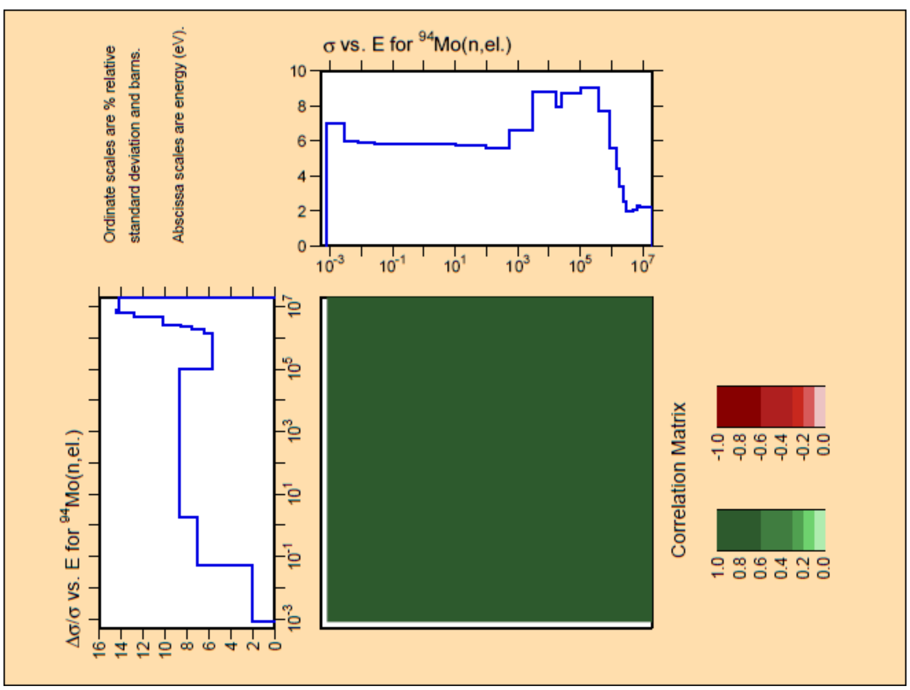

Figure C.23) ^{94}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

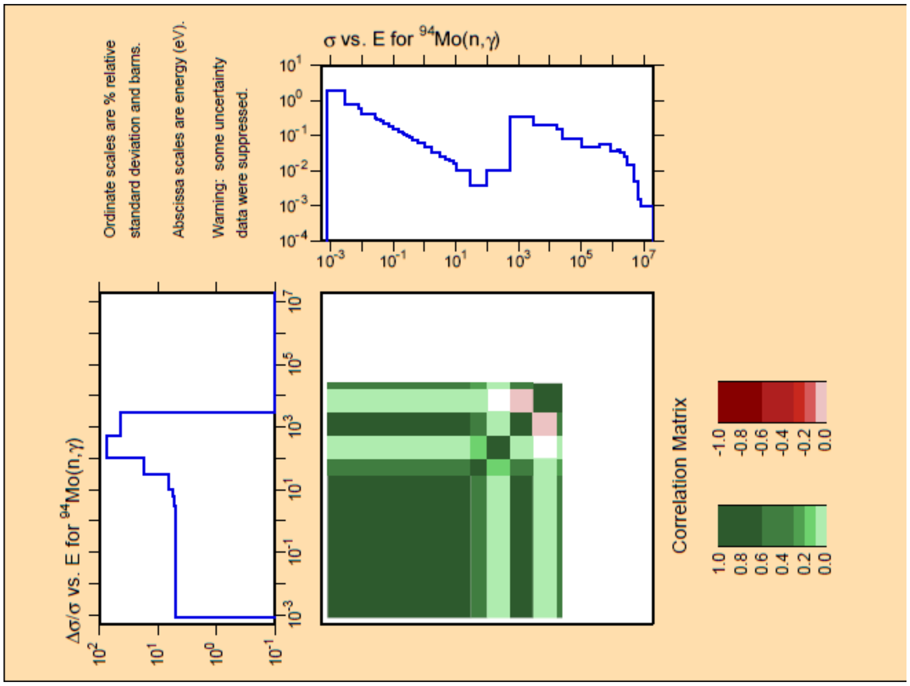

Figure C.24) ^{94}Mo Capture File 32 Covariance Data

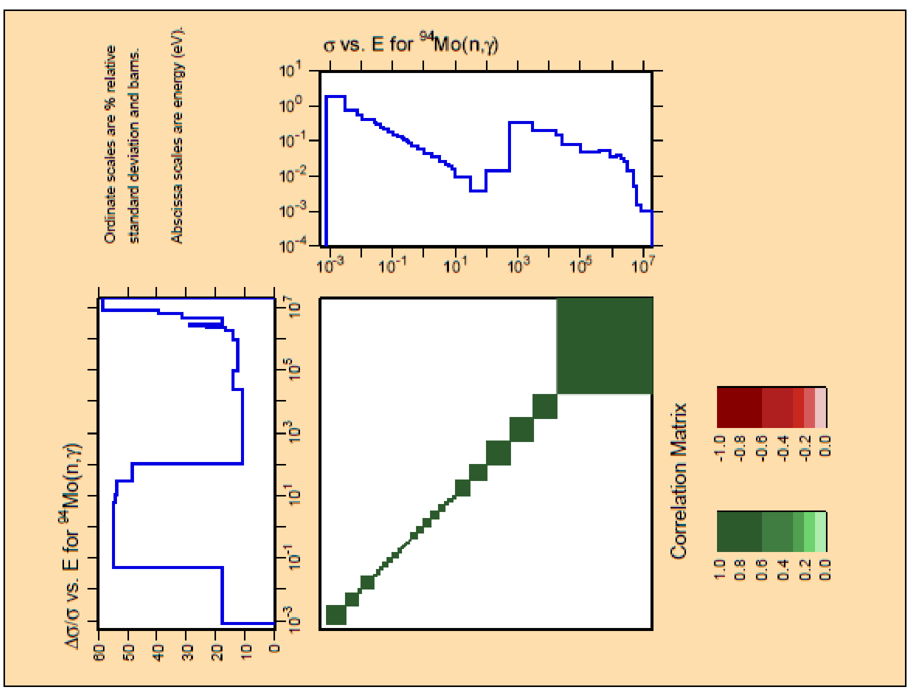

Figure C.25) ^{94}Mo Capture File 33 Covariance Data

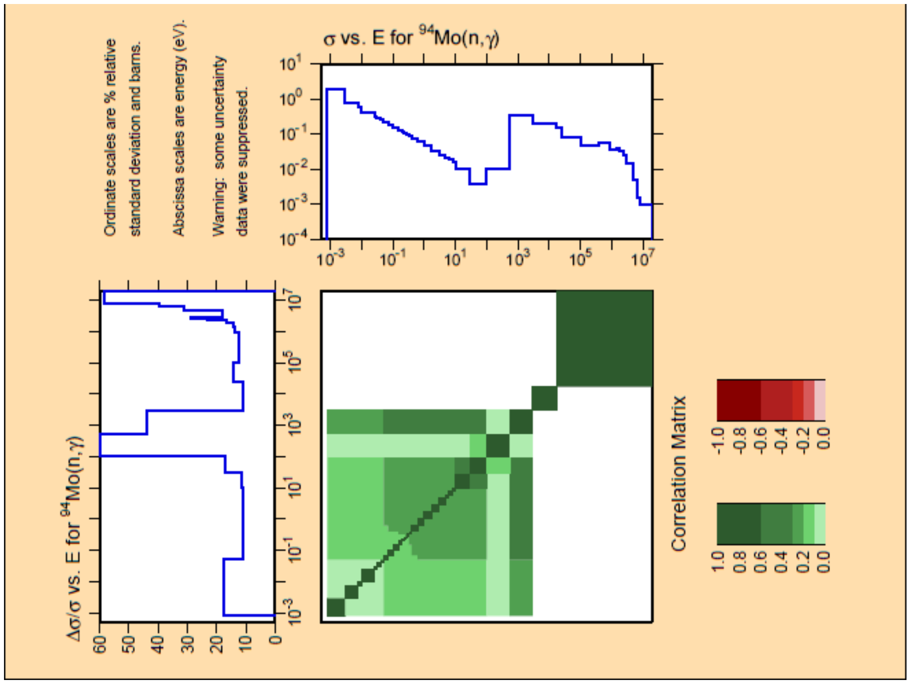

Figure C.26) ^{94}Mo CVDHCOV Capture Covariance Data

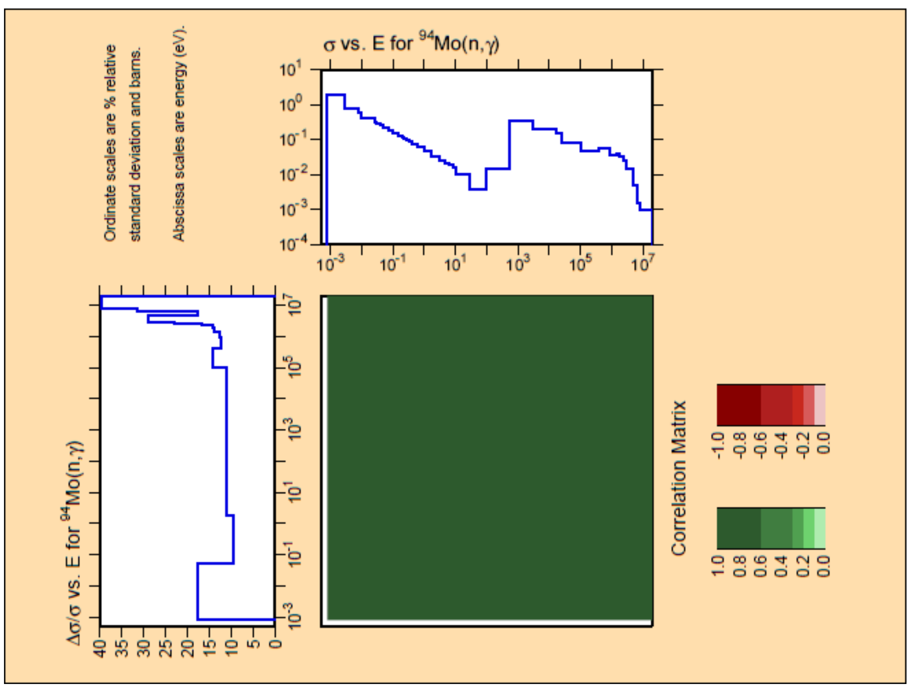

Figure C.27) ^{94}Mo LOFI Capture Covariance Data

^{95}Mo

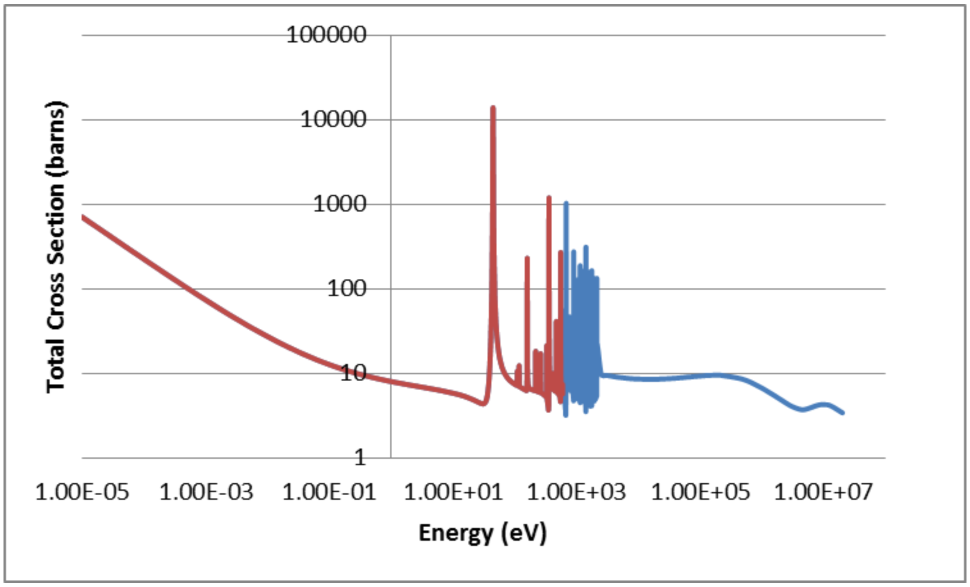

Figure C.28) ENDF/B-VII.1 ^{95}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

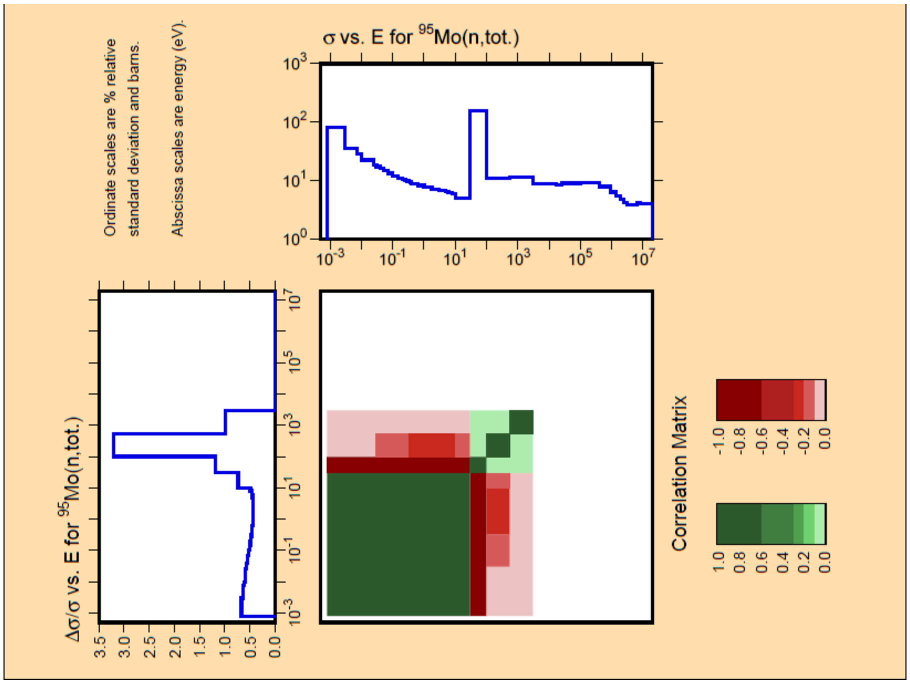

Figure C.29) ^{95}Mo Total File 32 Covariance Data

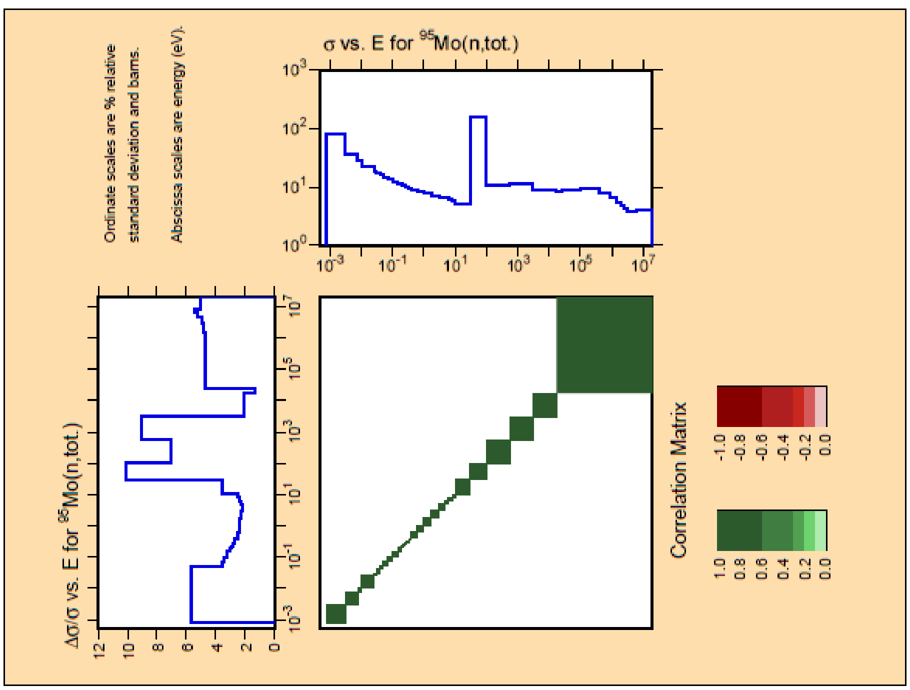

Figure C.30) ^{95}Mo Total File 33 Covariance Data

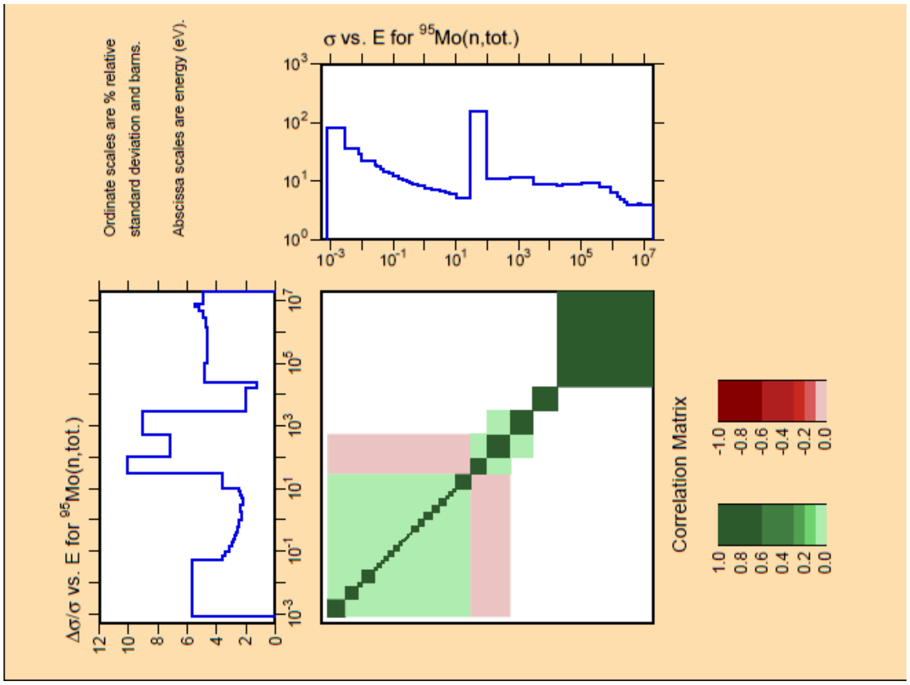

Figure C.31) ^{95}Mo CVDHCOV Total Covariance Data

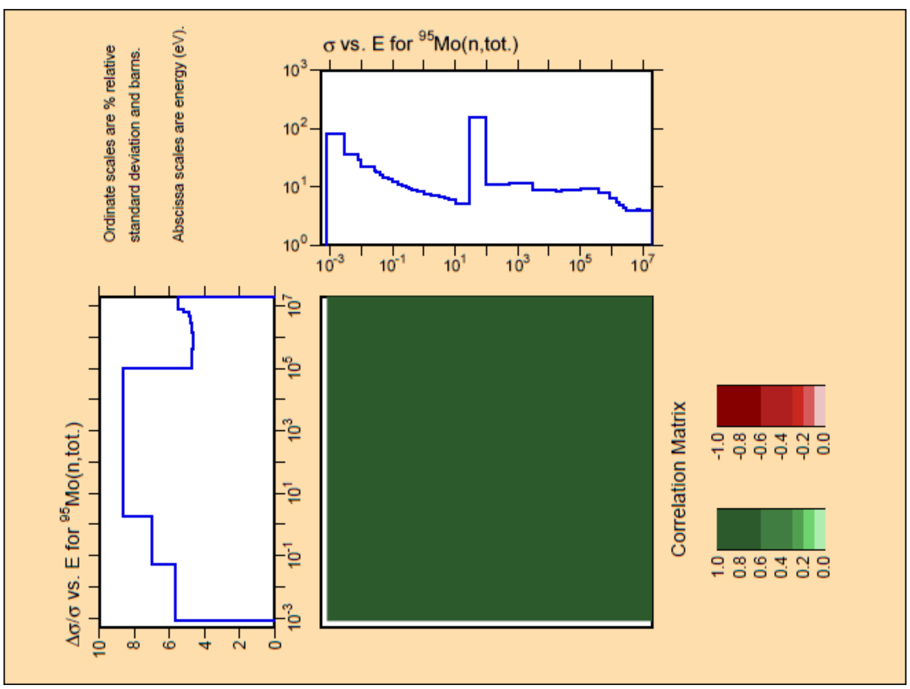

Figure C.32) ^{95}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

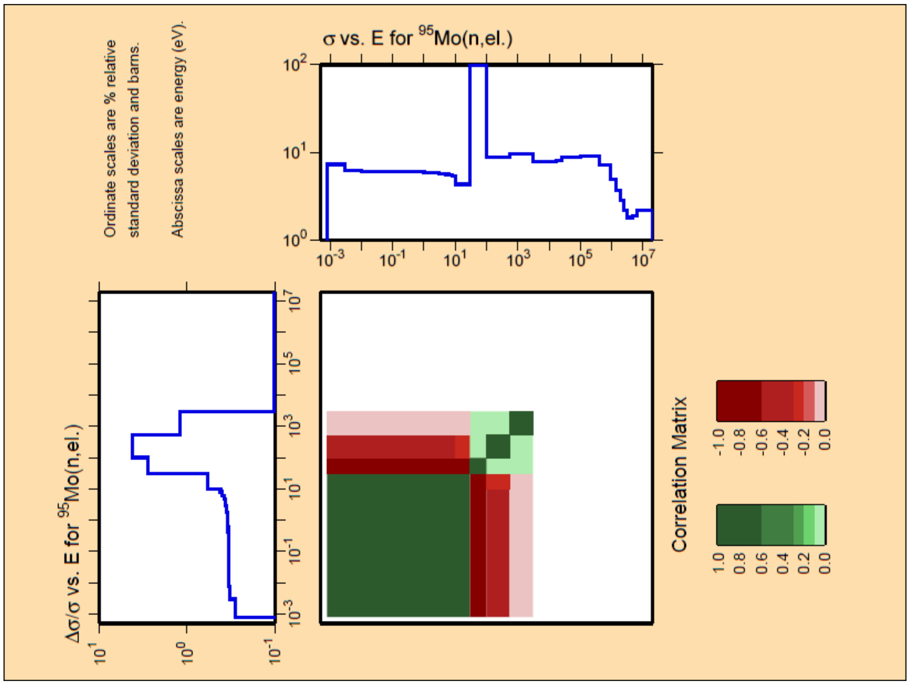

Figure C.33) ^{95}Mo Elastic Scattering File 32 Covariance Data

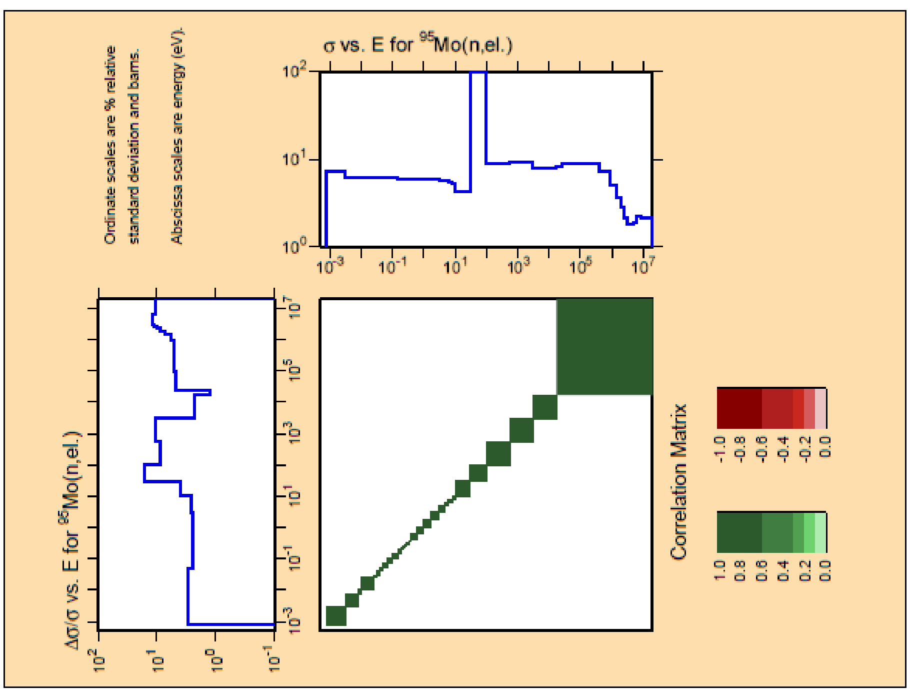

Figure C.34) ^{95}Mo Elastic Scattering File 33 Covariance Data

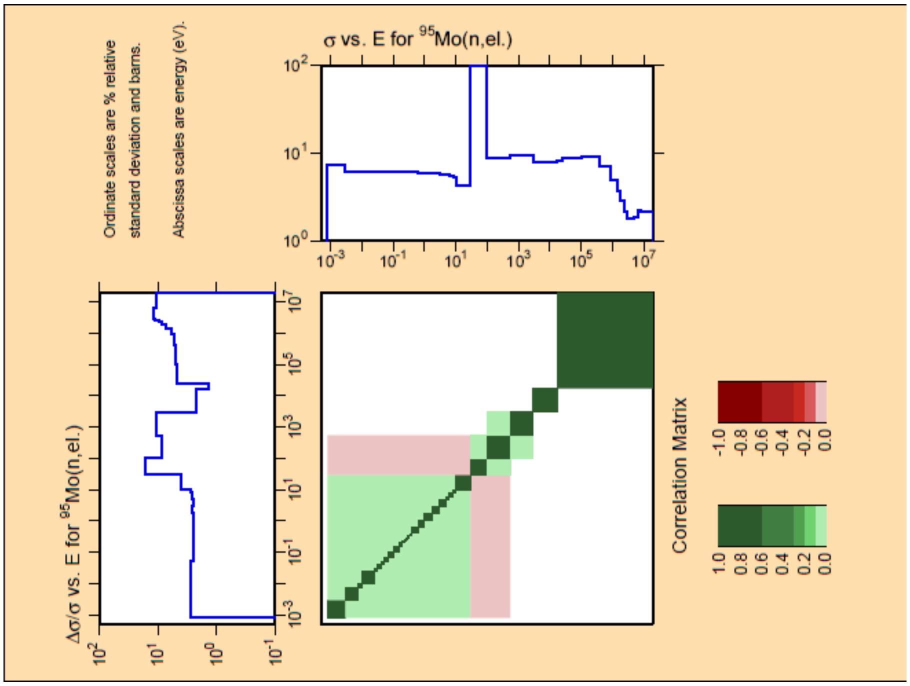

Figure C.35) ^{95}Mo CVDHCOV Elastic Scattering Covariance Data

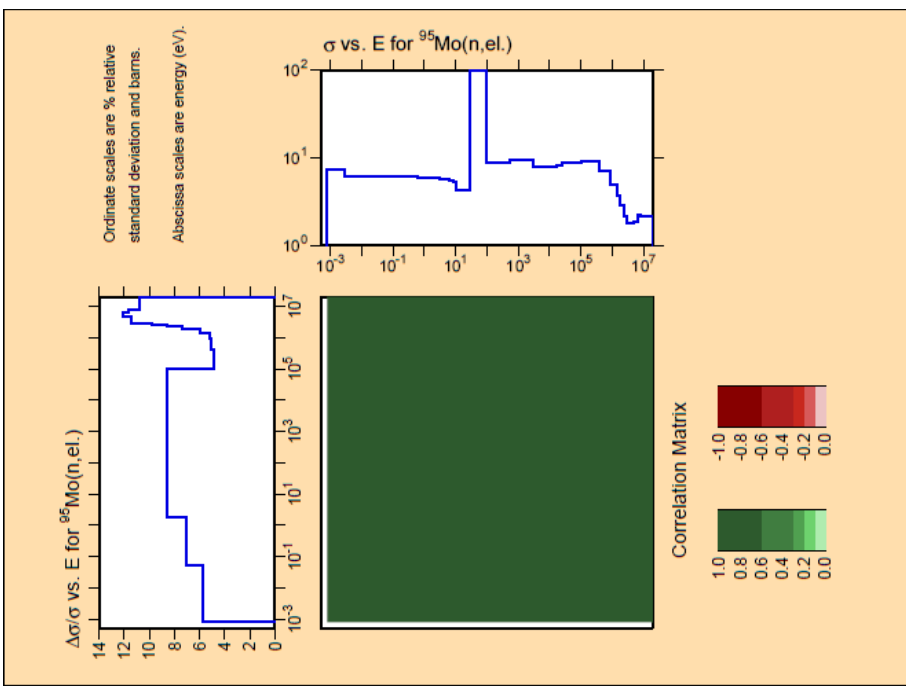

Figure C.36) ^{95}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

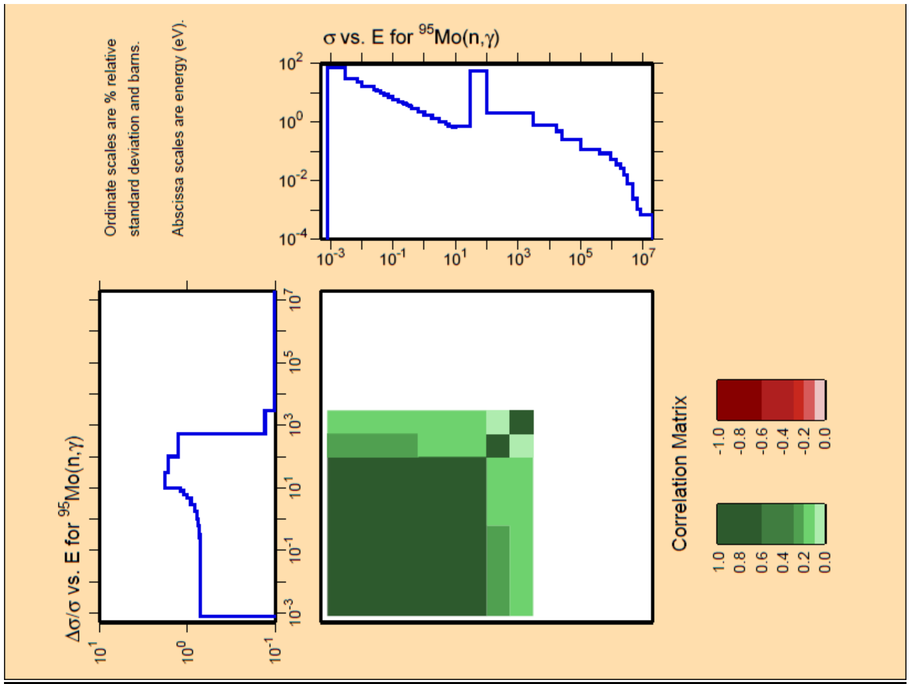

Figure C.37) ^{95}Mo Capture File 32 Covariance Data

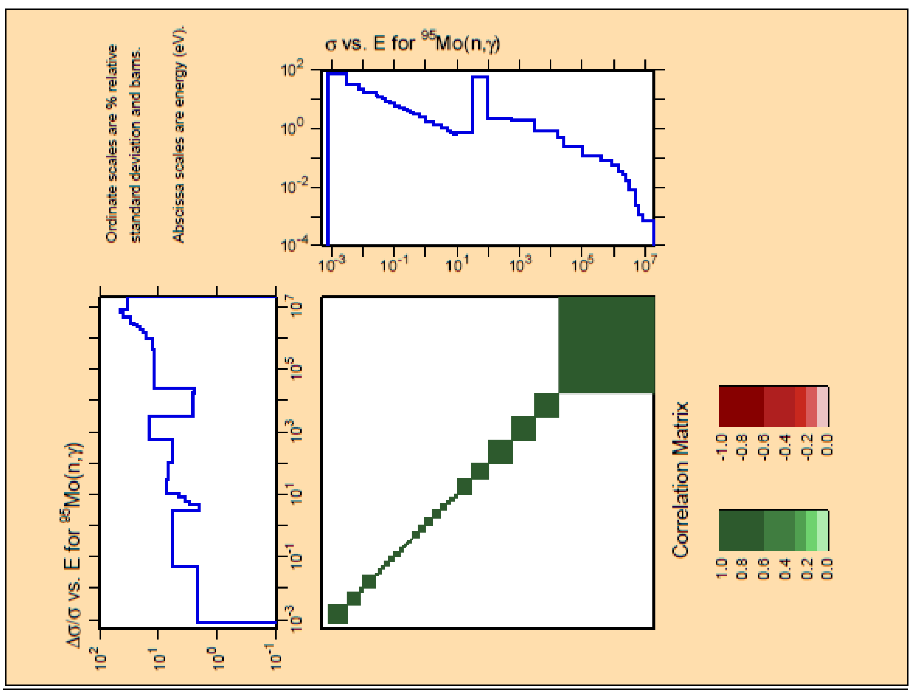

Figure C.38) ^{95}Mo Capture File 33 Covariance Data

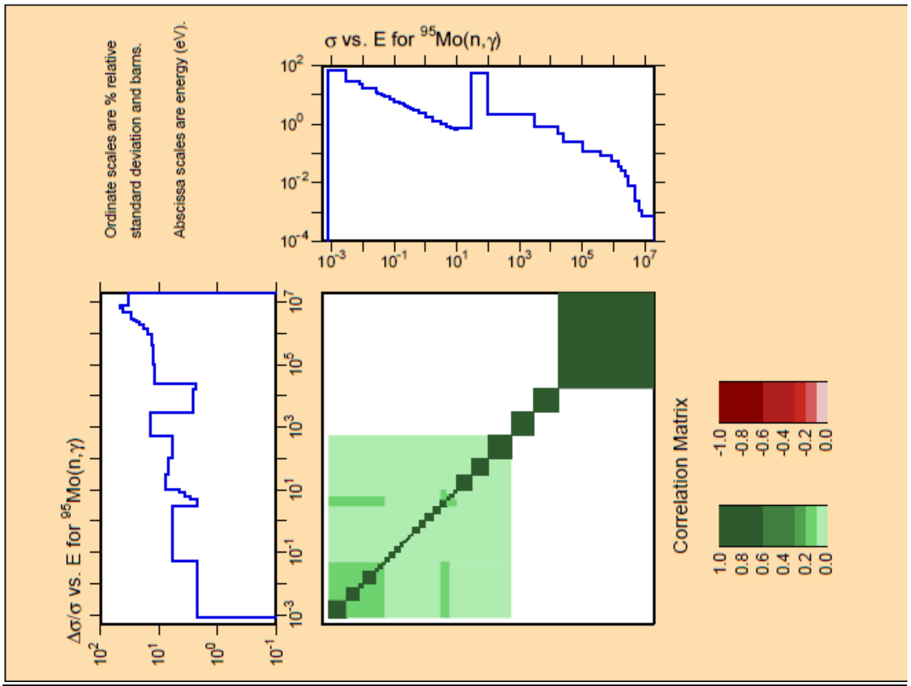

Figure C.39) ^{95}Mo CVDHCOV Capture Covariance Data

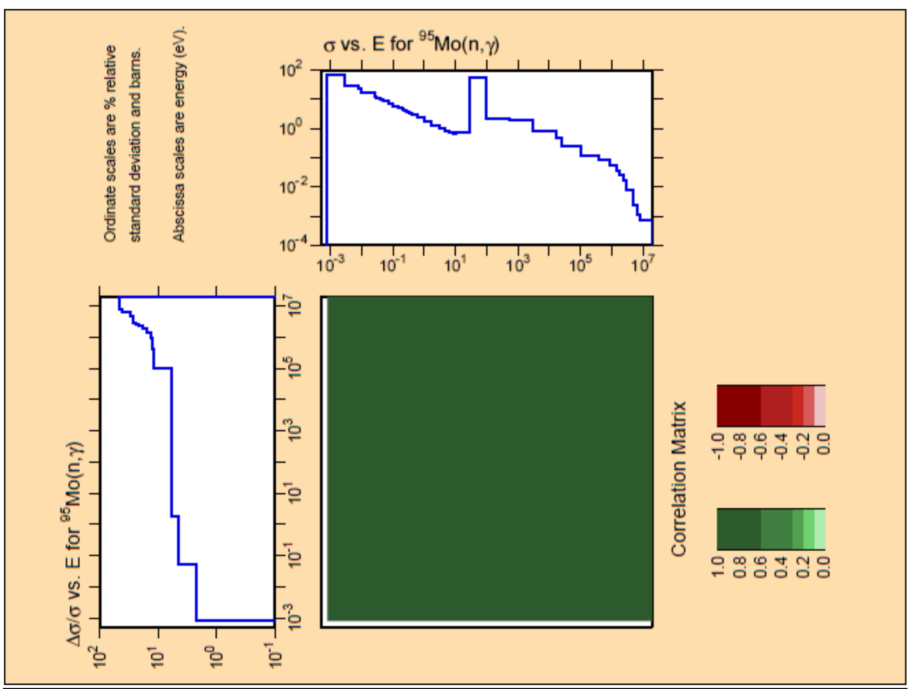

Figure C.40) ^{95}Mo LOFI Capture Covariance Data

^{96}Mo

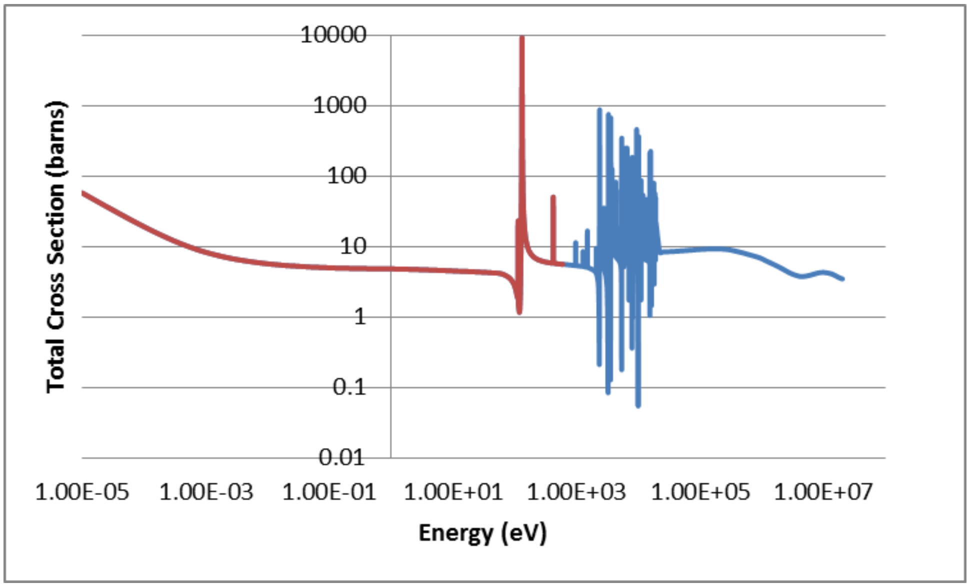

Figure C.41) ENDF/B-VII.1 ^{96}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

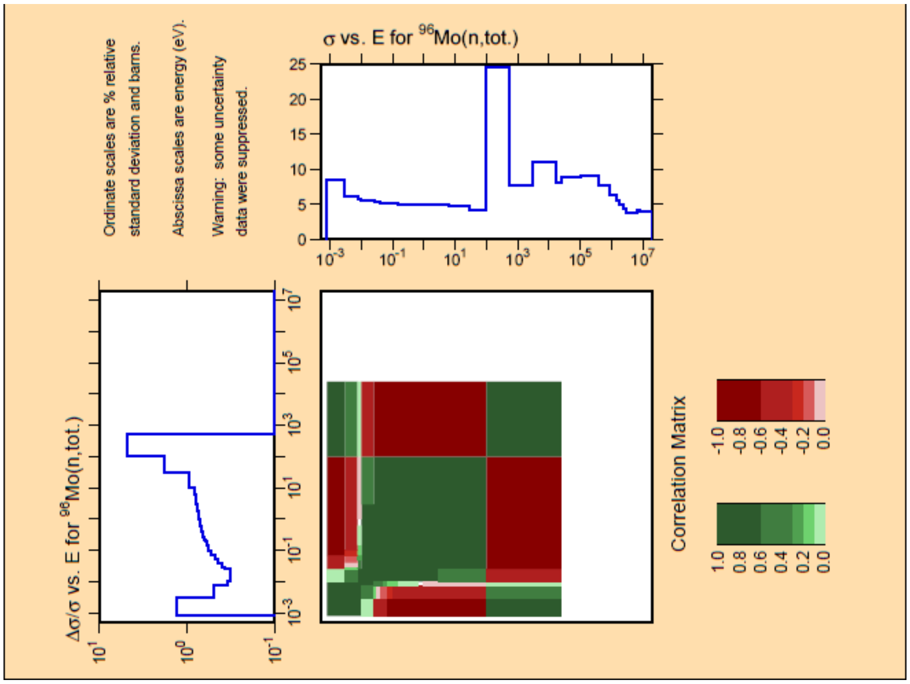

Figure C.42) ^{96}Mo Total File 32 Covariance Data

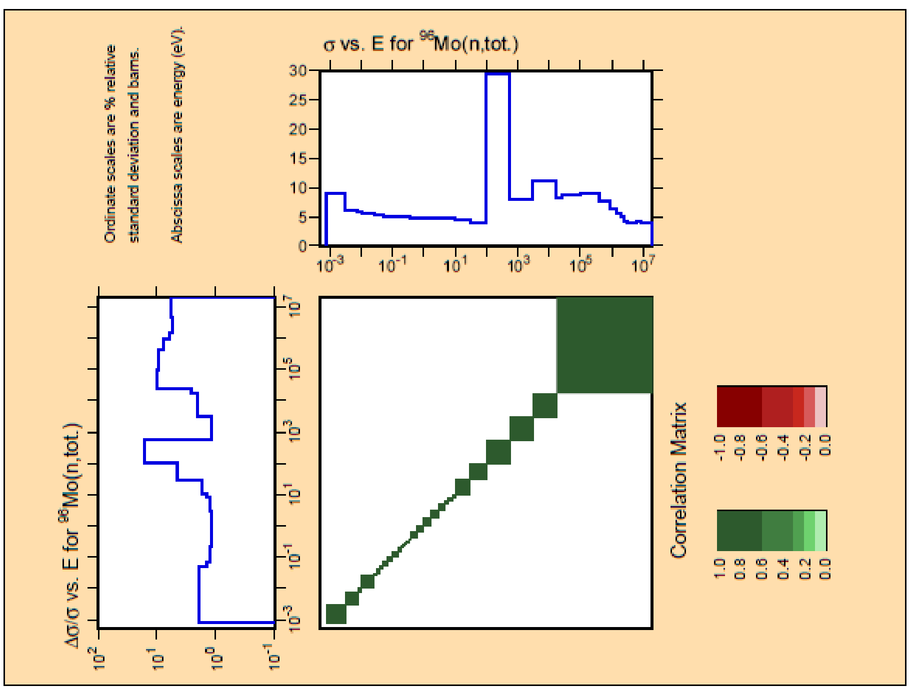

Figure C.43) ^{96}Mo Total File 33 Covariance Data

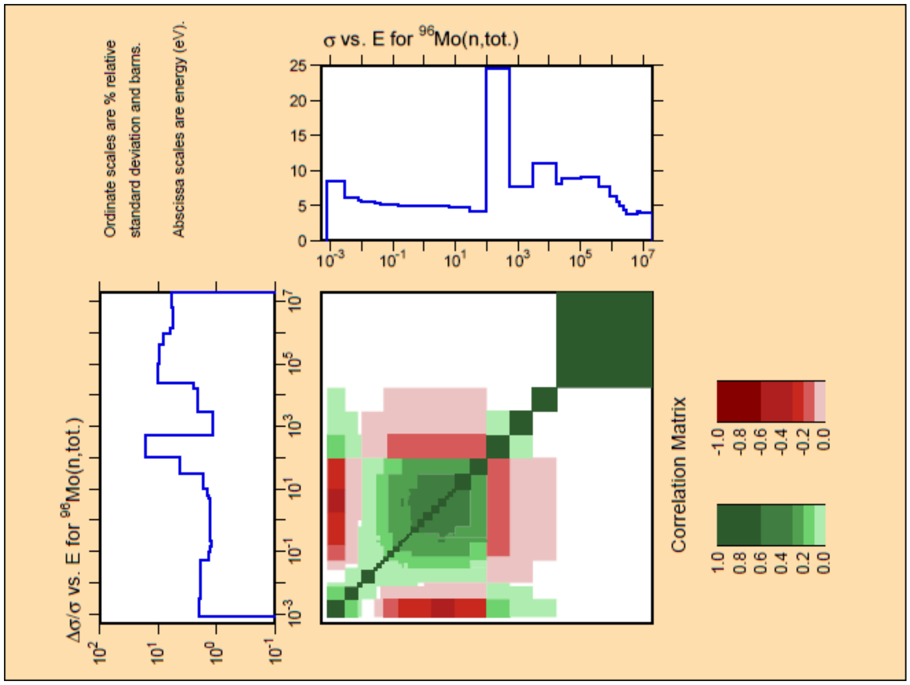

Figure C.44) ^{96}Mo CVDHCOV Total Covariance Data

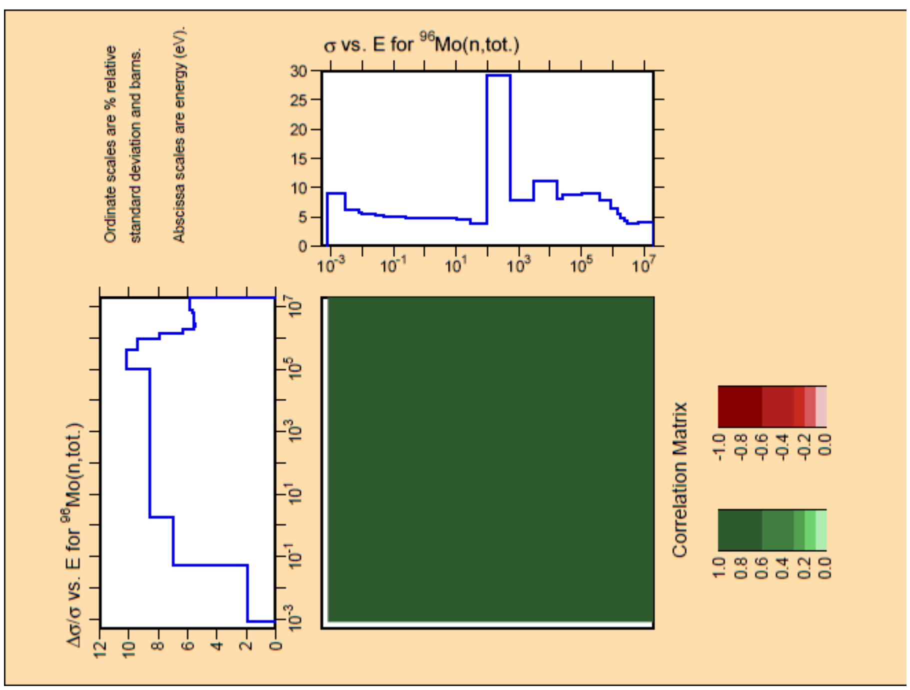

Figure C.45) ^{96}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

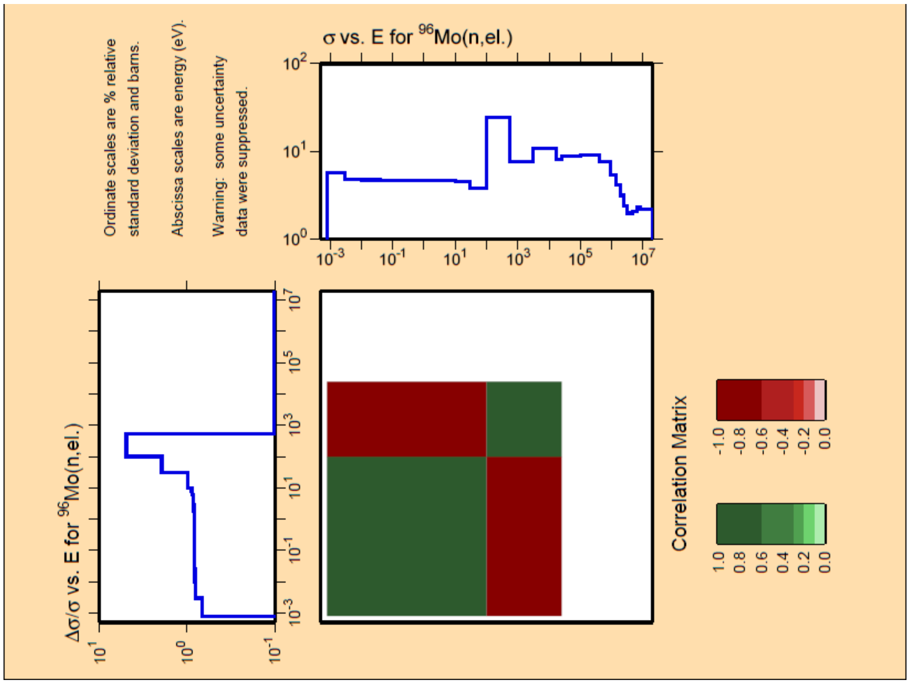

Figure C.46) ^{96}Mo Elastic Scattering File 32 Covariance Data

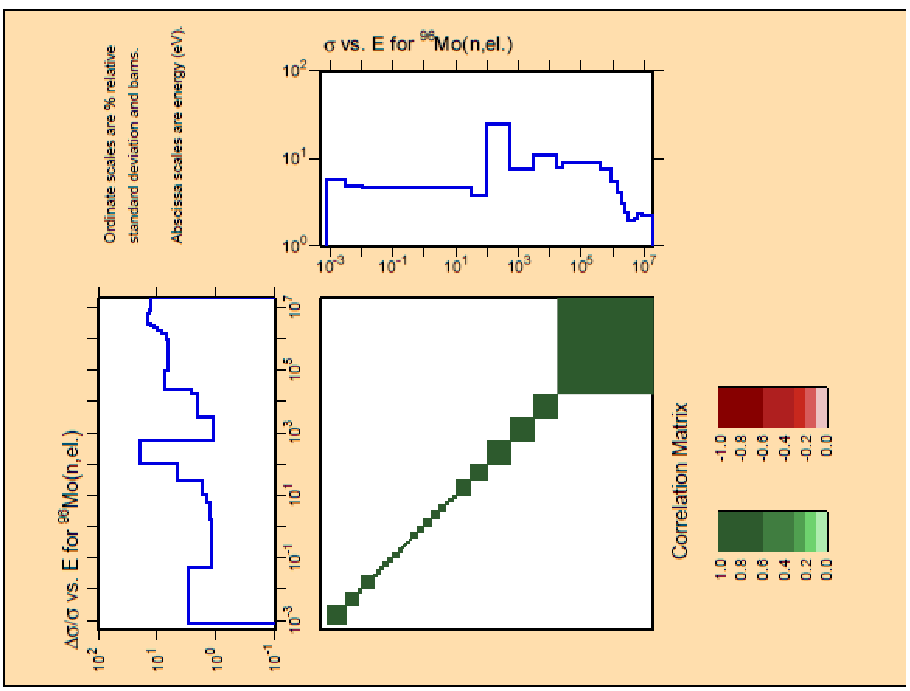

Figure C.47) ^{96}Mo Elastic Scattering File 33 Covariance Data

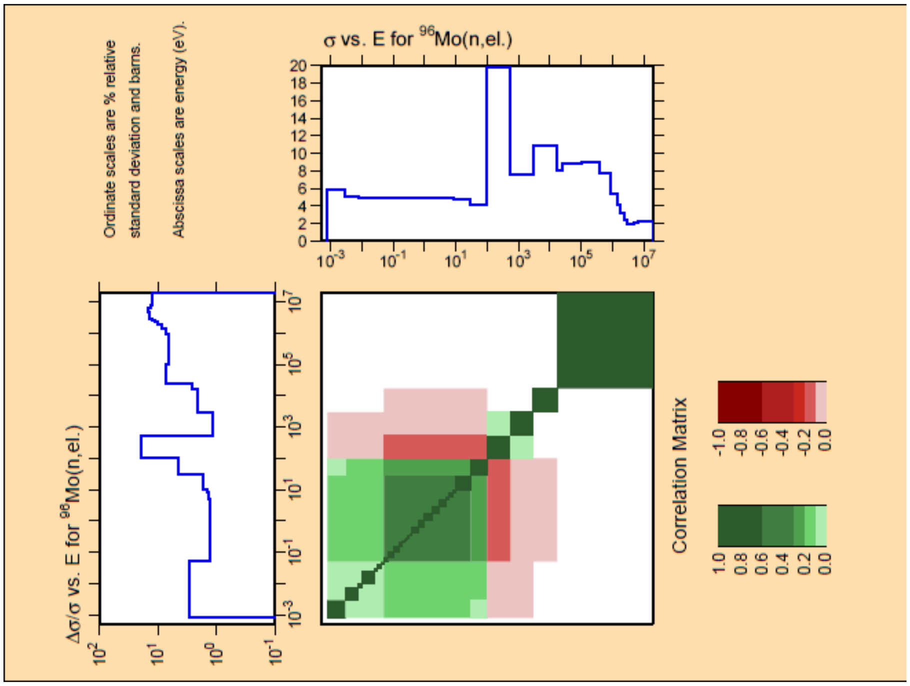

Figure C.48) ^{96}Mo CVDHCOV Elastic Scattering Covariance Data

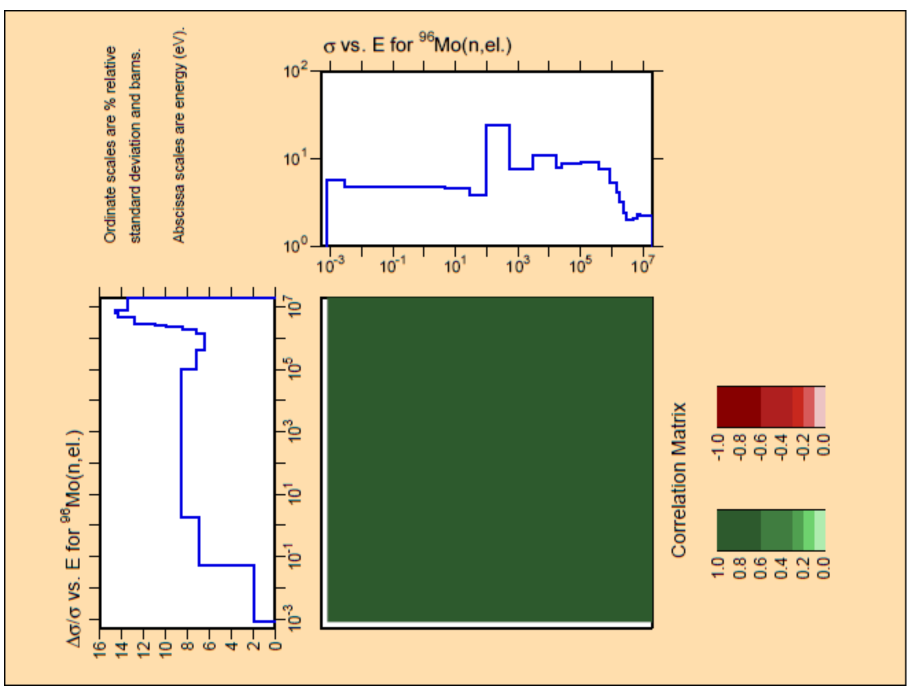

Figure C.49) ^{96}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

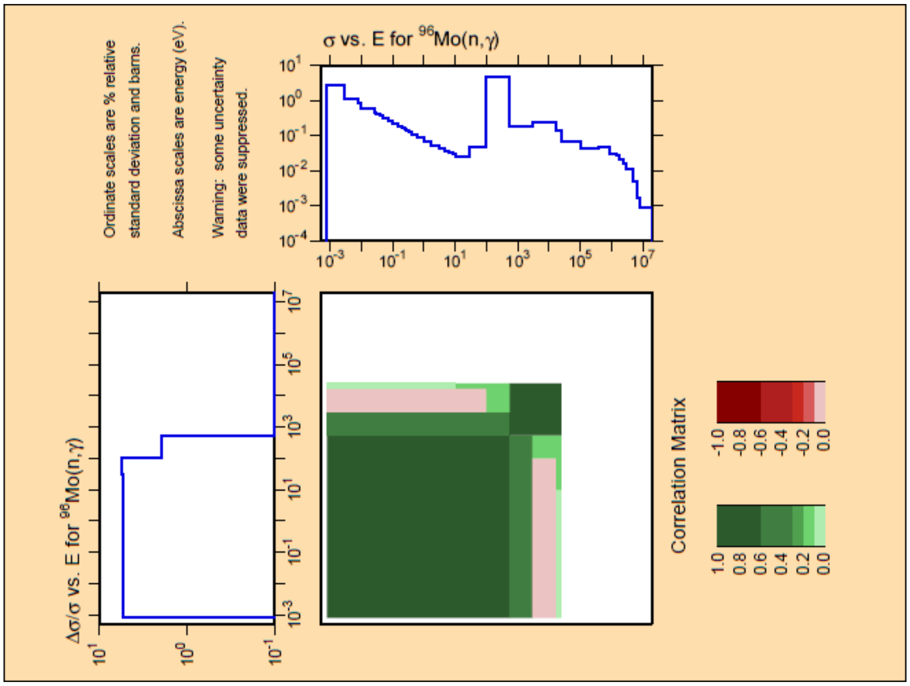

Figure C.50) ^{96}Mo Capture File 32 Covariance Data

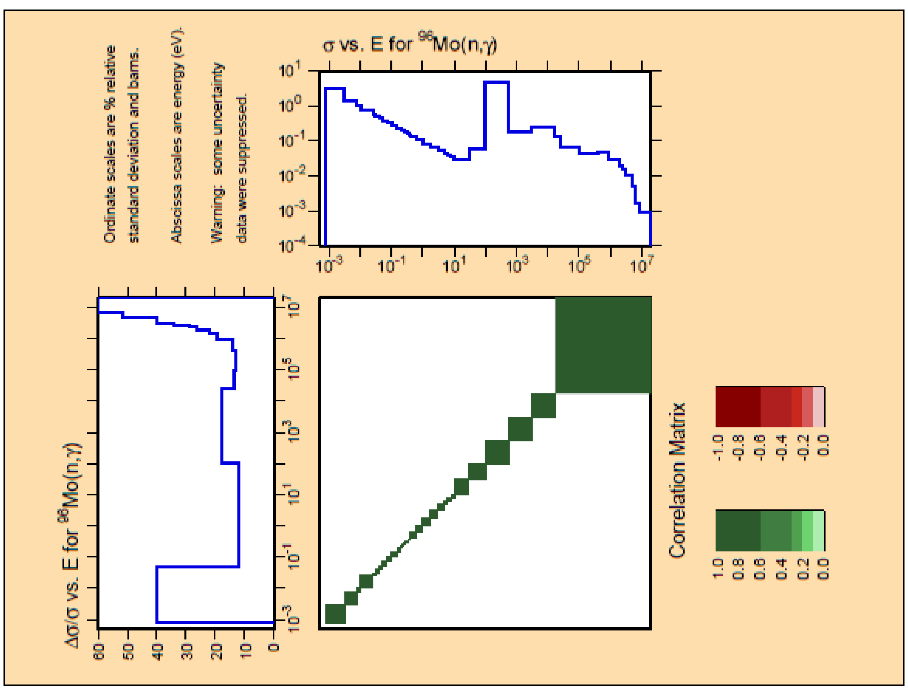

Figure C.51) ^{96}Mo Capture File 33 Covariance Data

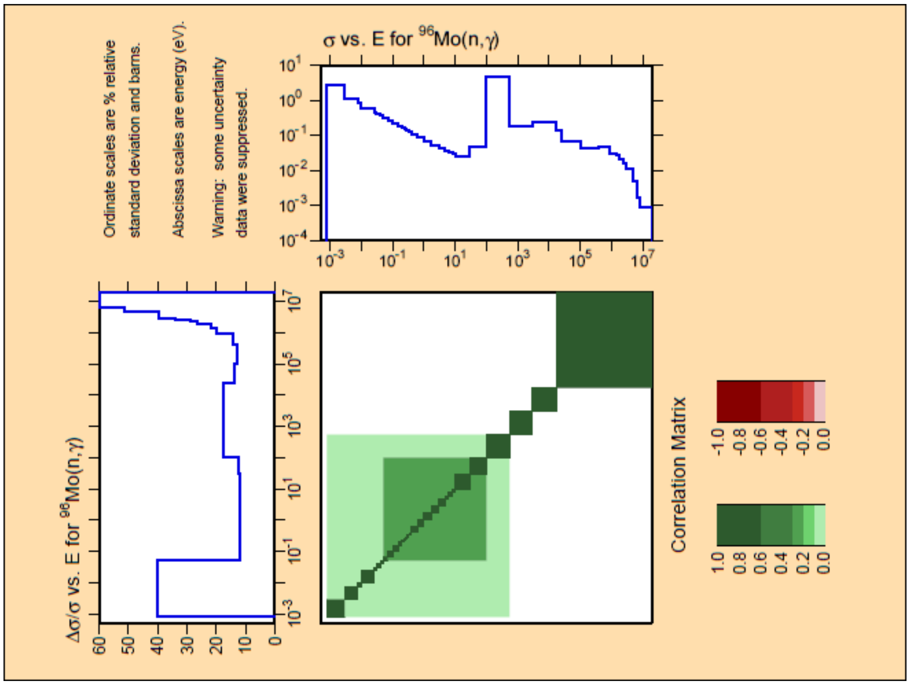

Figure C.52) ^{96}Mo CVDHCOV Capture Covariance Data

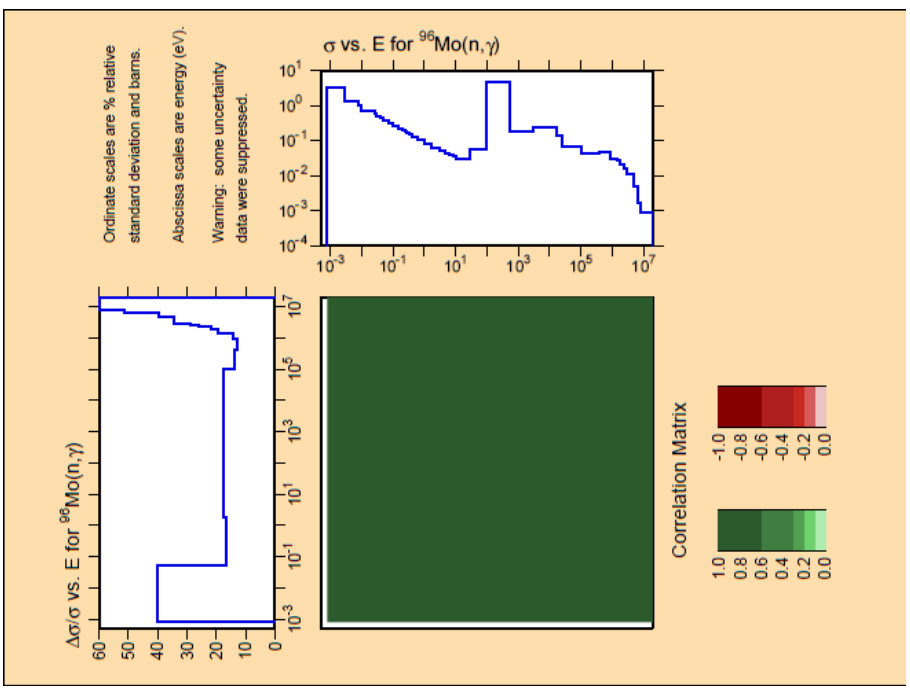

Figure C.53) ^{96}Mo LOFI Capture Covariance Data

^{97}Mo

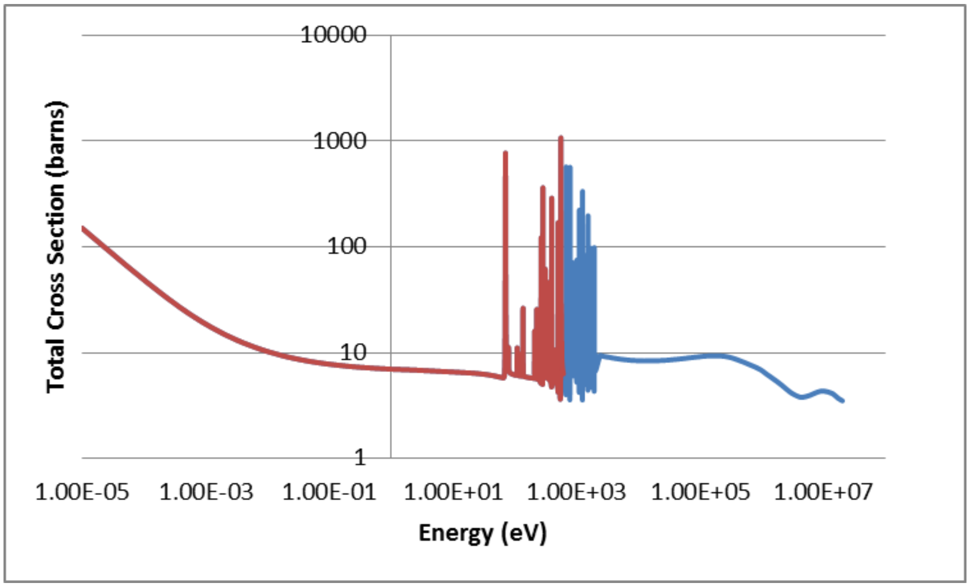

Figure C.54) ENDF/B-VII.1 ^{97}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

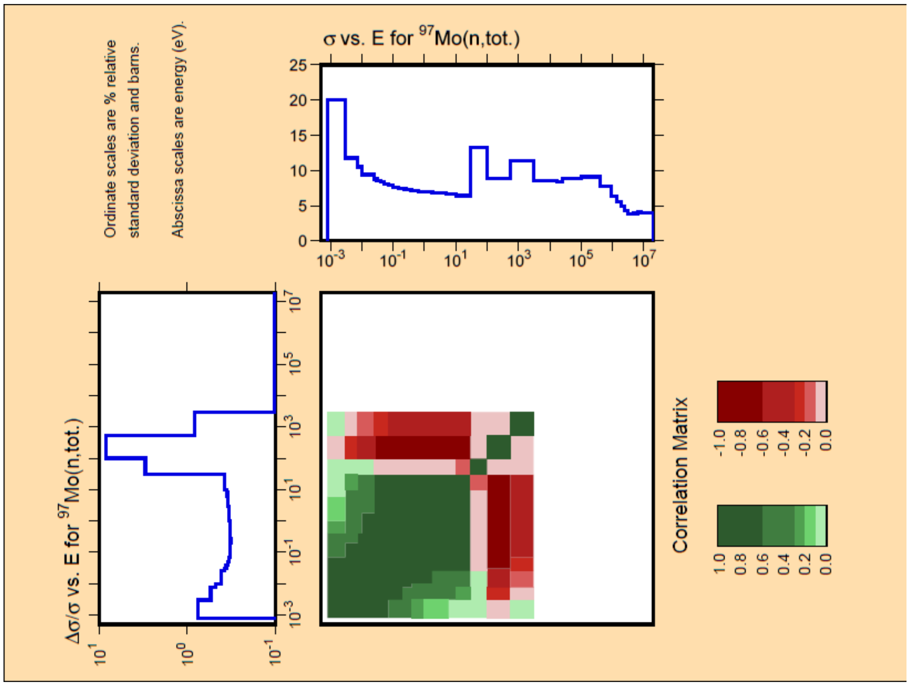

Figure C.55) ^{97}Mo Total File 32 Covariance Data

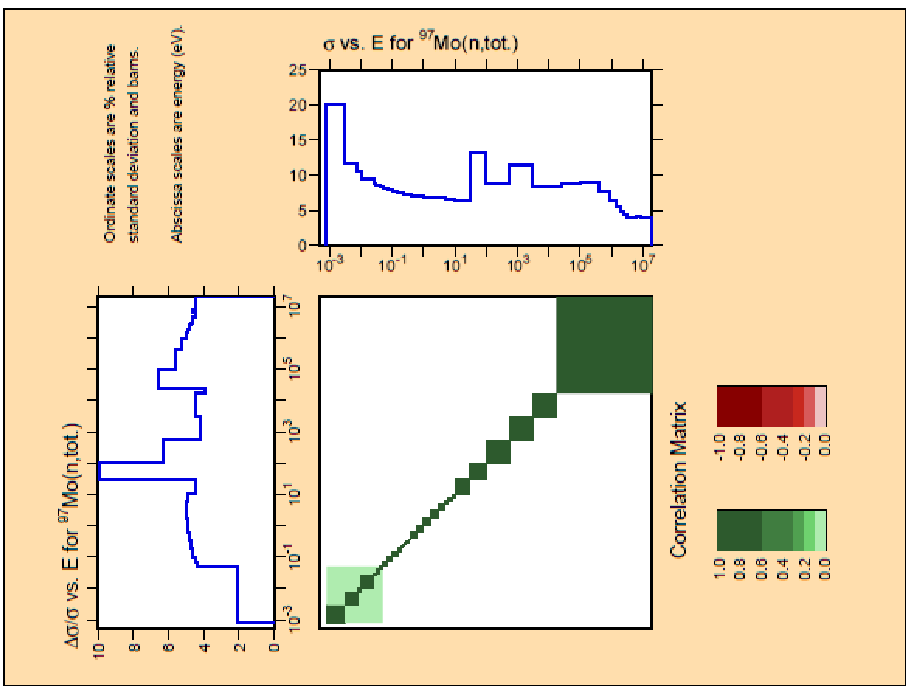

Figure C.56) ^{97}Mo Total File 33 Covariance Data

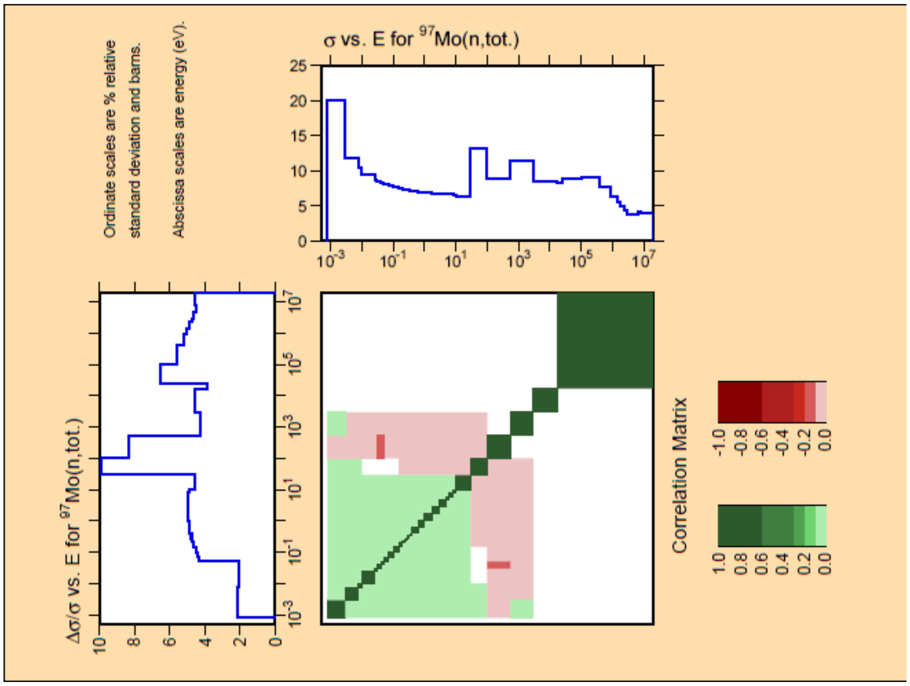

Figure C.57) ^{97}Mo CVDHCOV Total Covariance Data

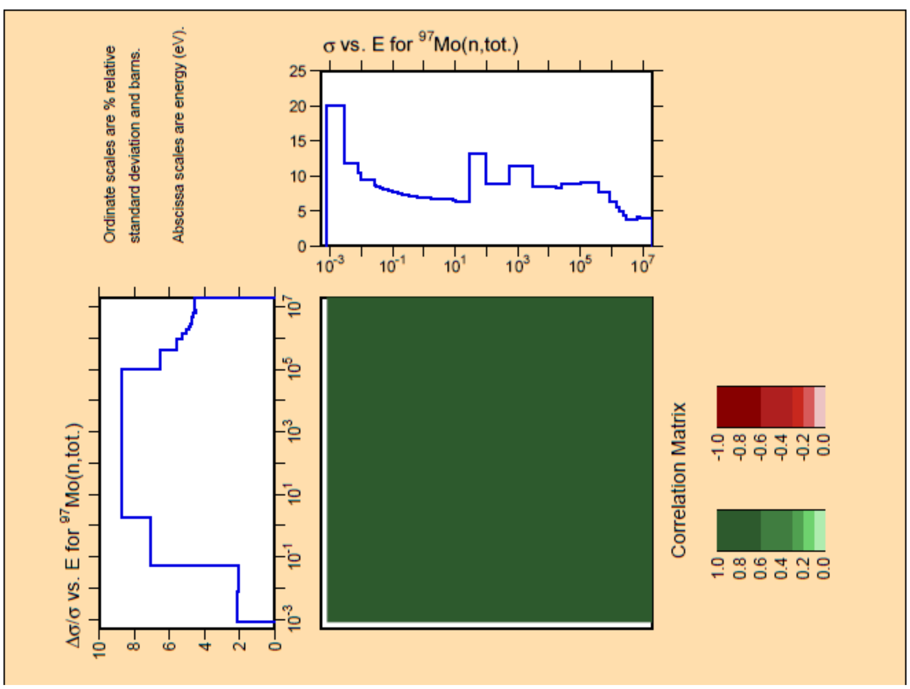

Figure C.58) ^{97}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

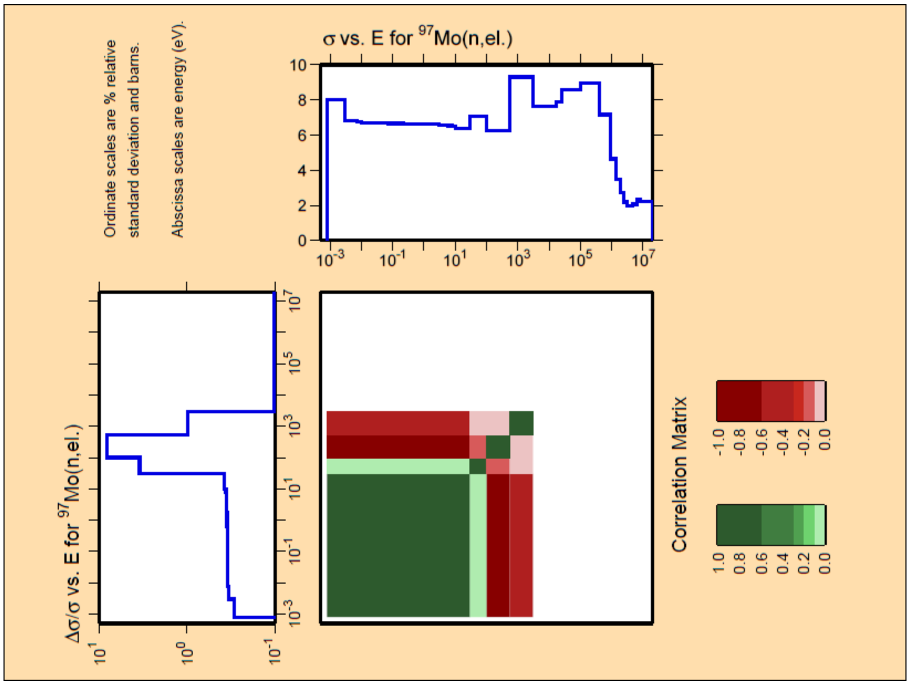

Figure C.59) ^{97}Mo Elastic Scattering File 32 Covariance Data

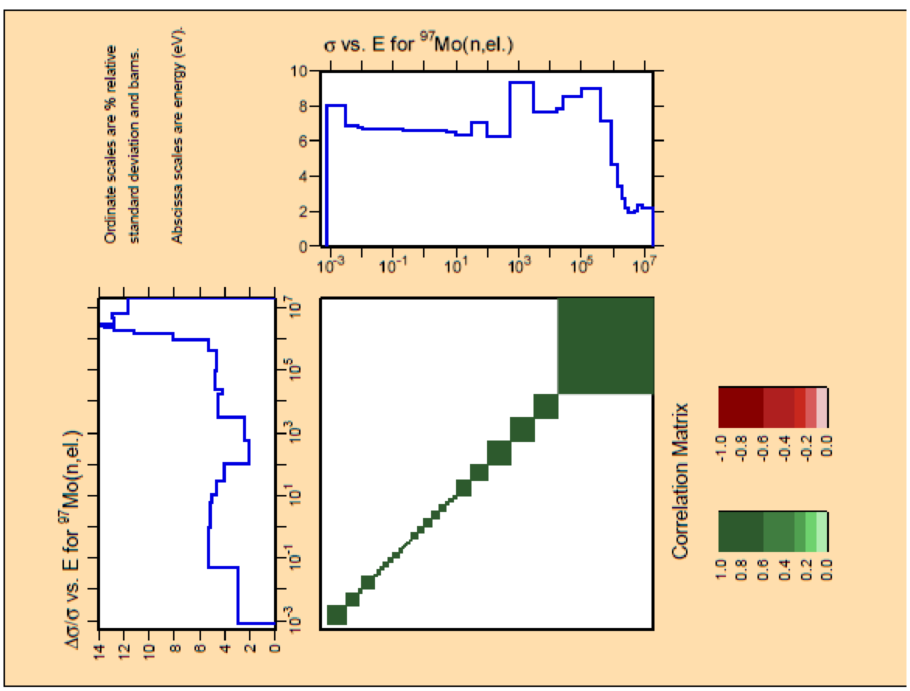

Figure C.60) ^{97}Mo Elastic Scattering File 33 Covariance Data

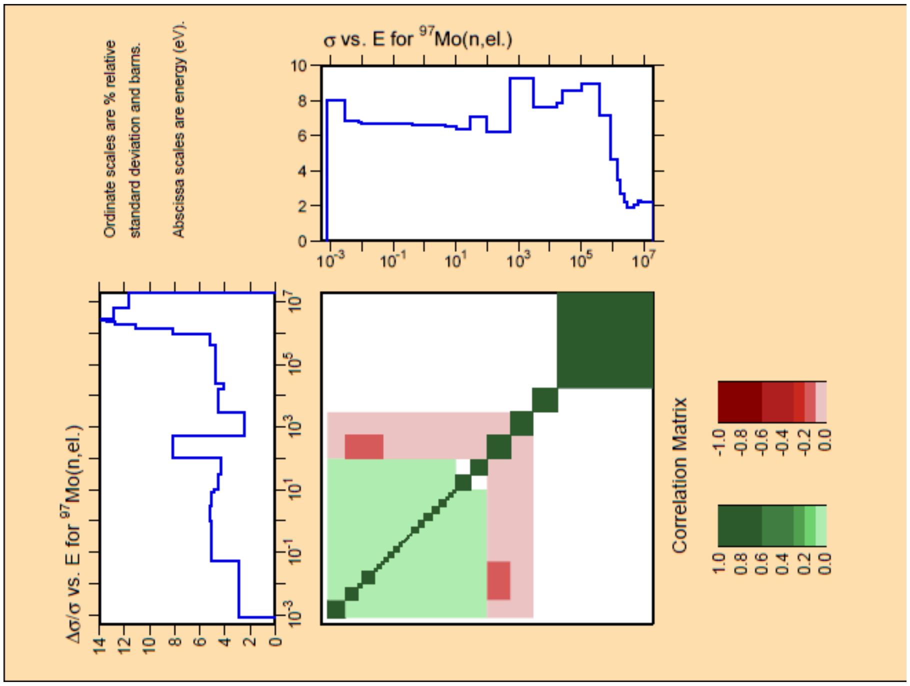

Figure C.61) ^{97}Mo CVDHCOV Elastic Scattering Covariance Data

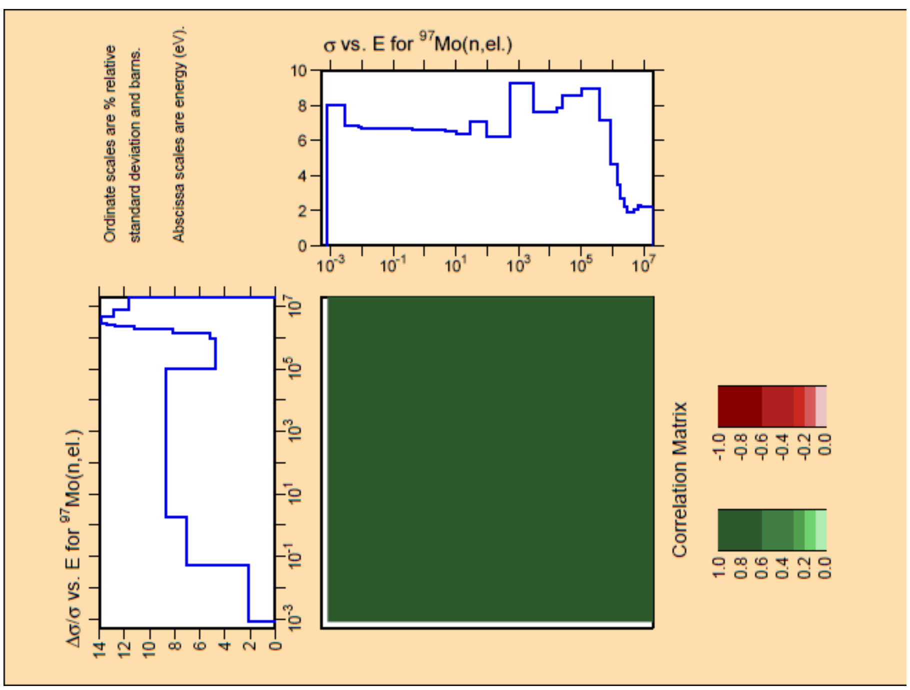

Figure C.62) ^{97}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

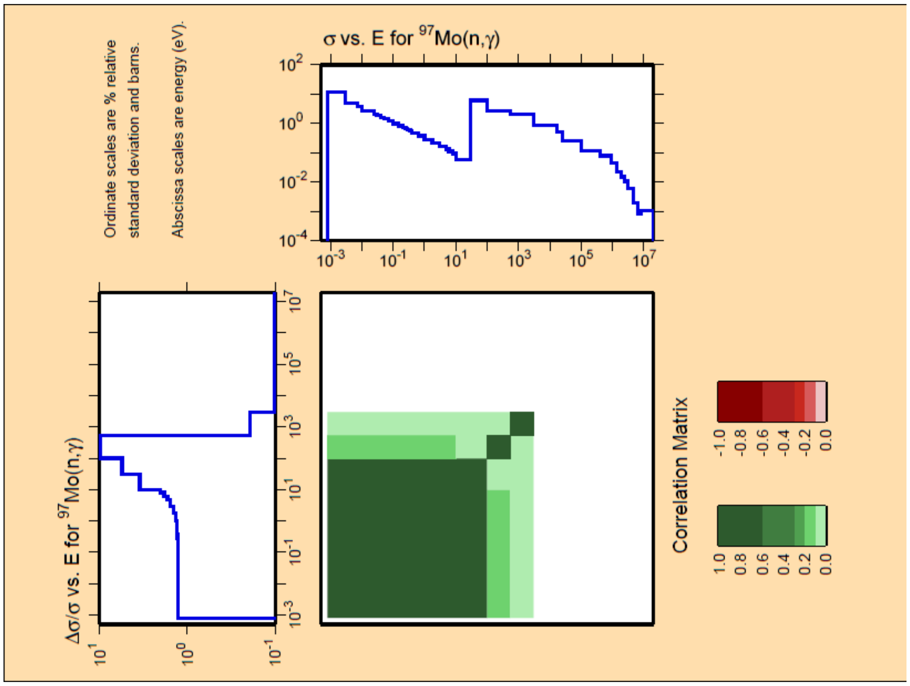

Figure C.63) ^{97}Mo Capture File 32 Covariance Data

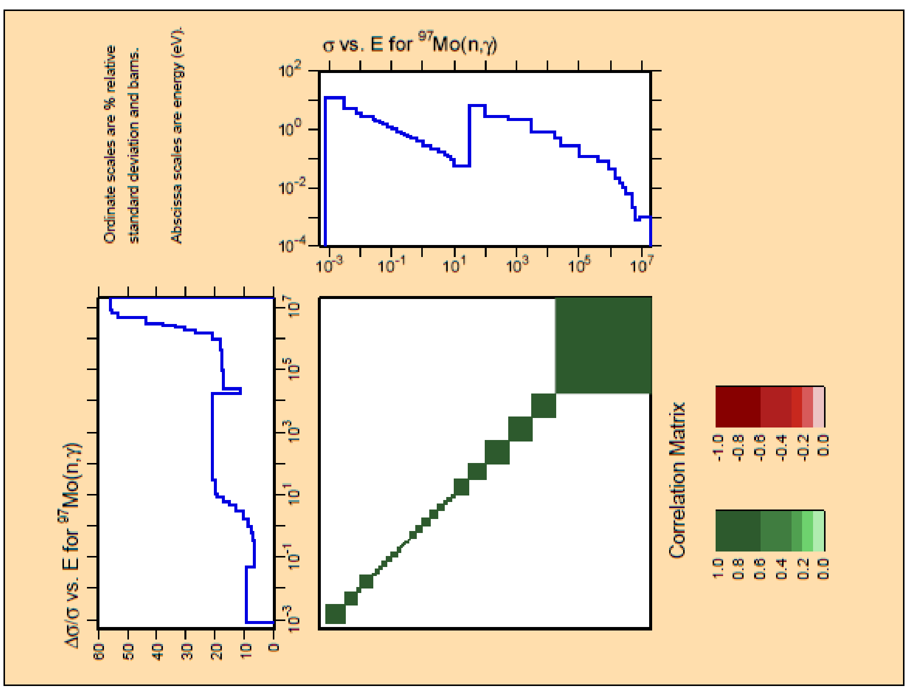

Figure C.64) ^{97}Mo Capture File 33 Covariance Data

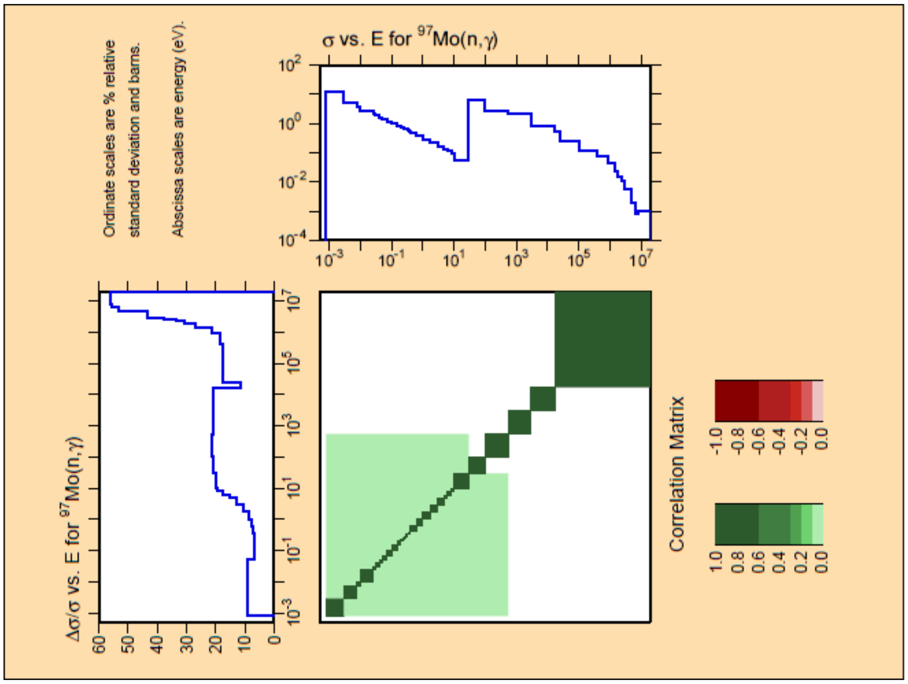

Figure C.65) ^{97}Mo CVDHCOV Capture Covariance Data

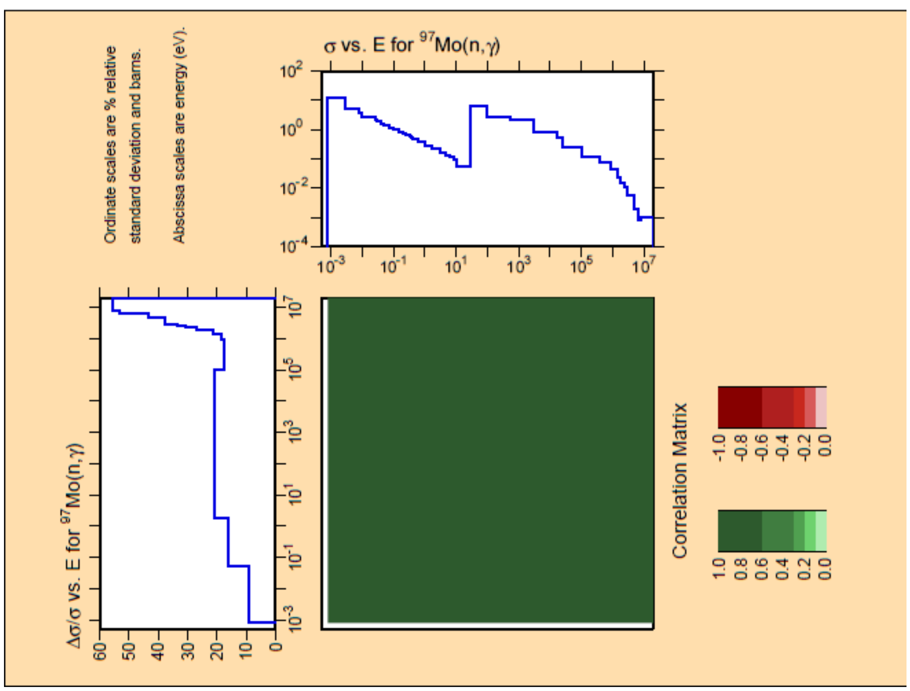

Figure C.66) ^{97}Mo LOFI Capture Covariance Data

^{98}Mo

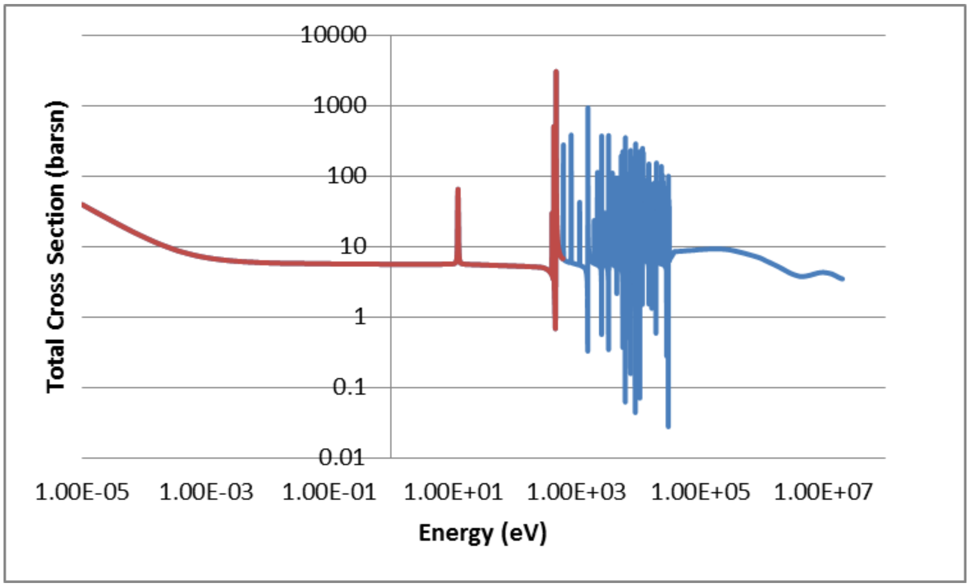

Figure C.67) ENDF/B-VII.1 ^{98}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

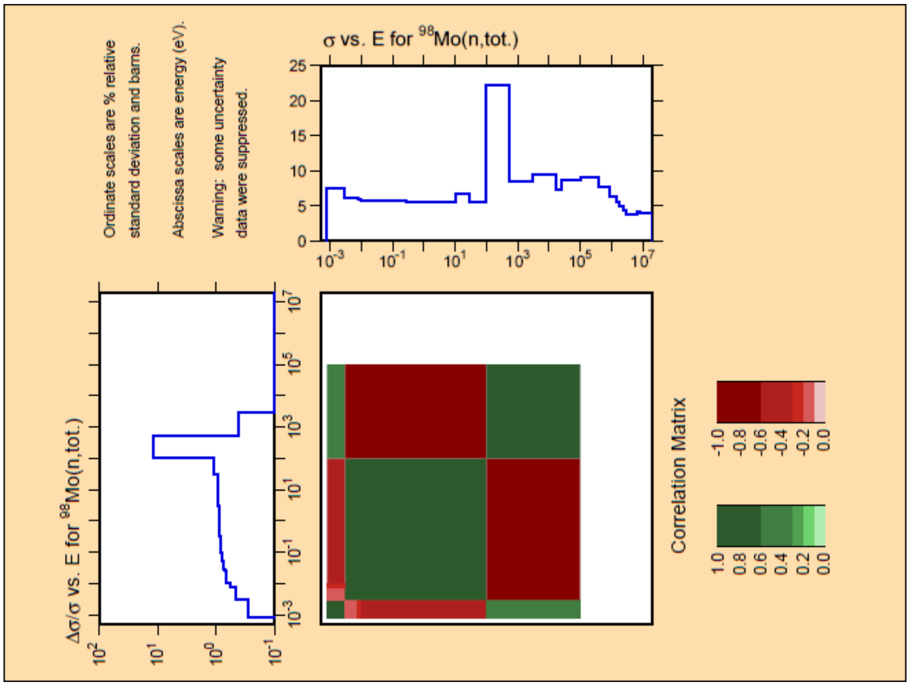

Figure C.68) ^{98}Mo Total File 32 Covariance Data

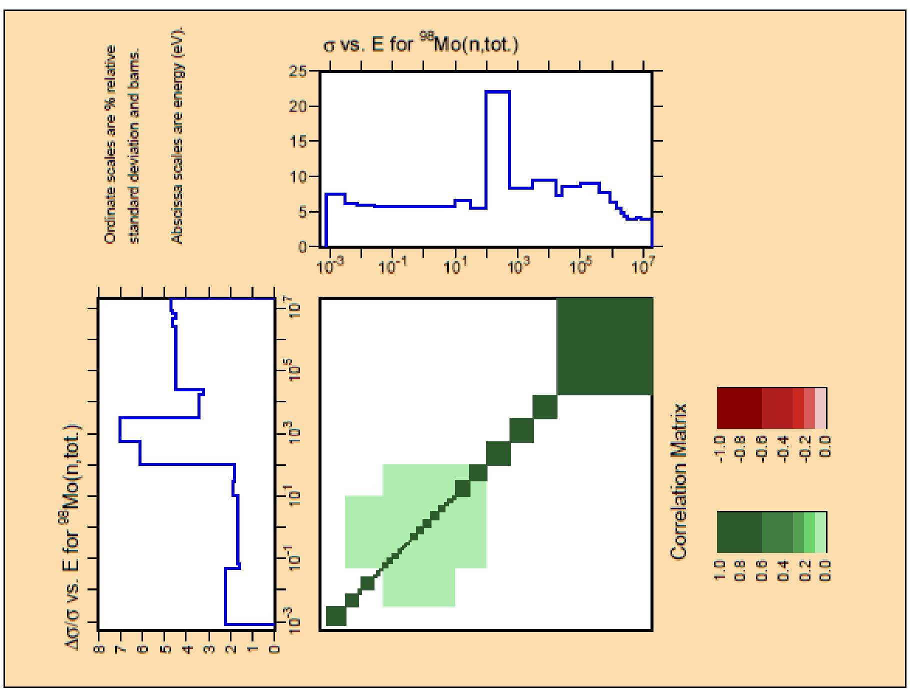

Figure C.69) ^{98}Mo Total File 33 Covariance Data

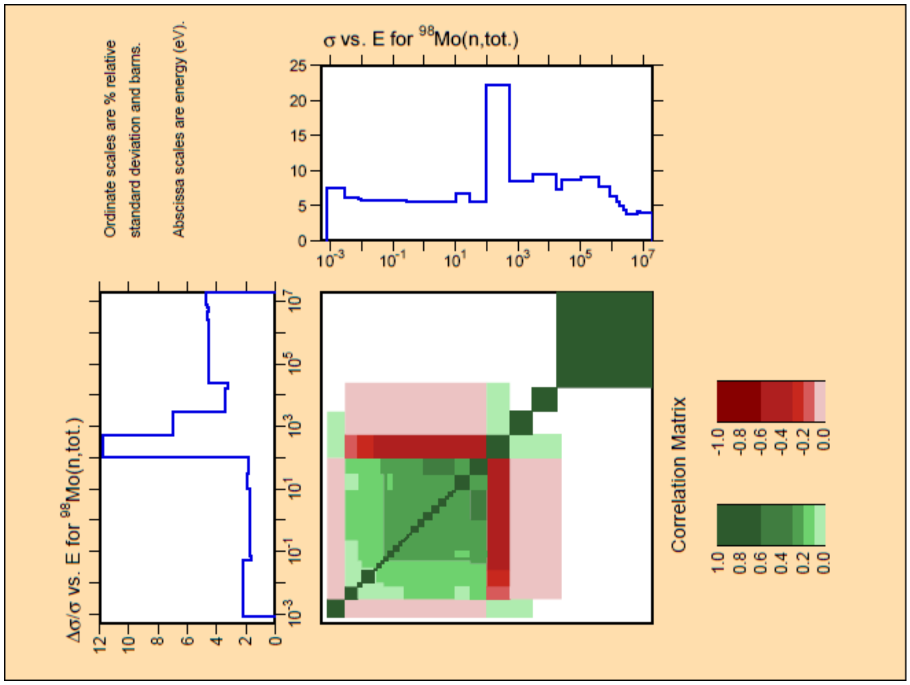

Figure C.70) ^{98}Mo CVDHCOV Total Covariance Data

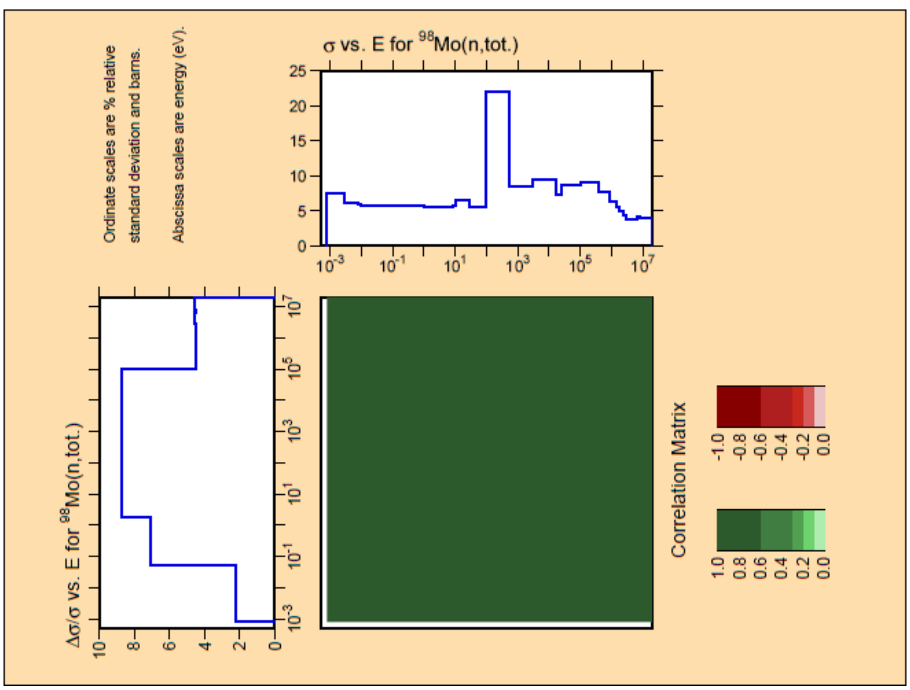

Figure C.71) ^{98}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

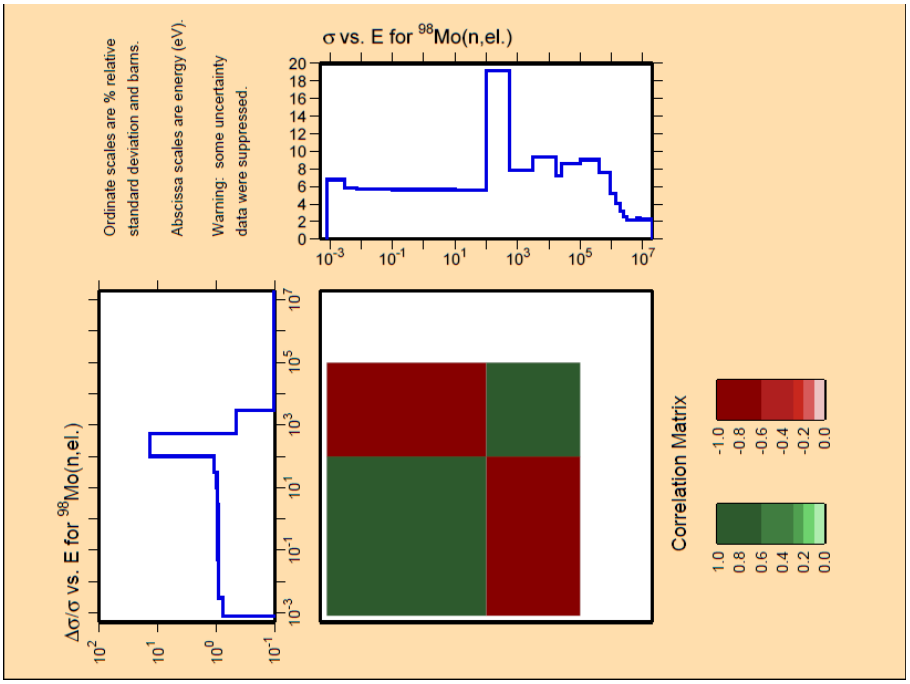

Figure C.72) ^{98}Mo Elastic Scattering File 32 Covariance Data

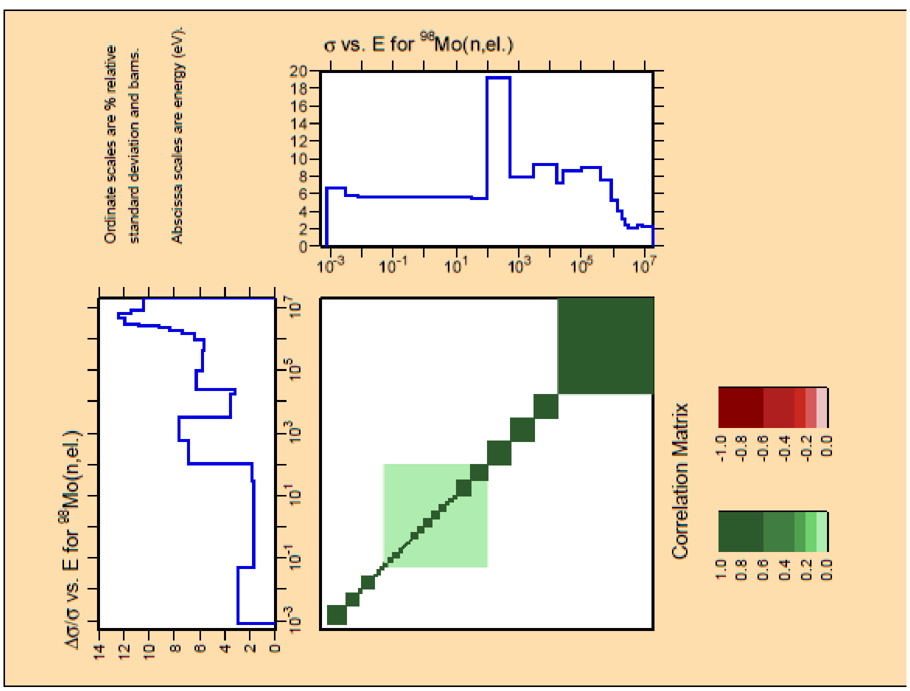

Figure C.73) ^{98}Mo Elastic Scattering File 33 Covariance Data

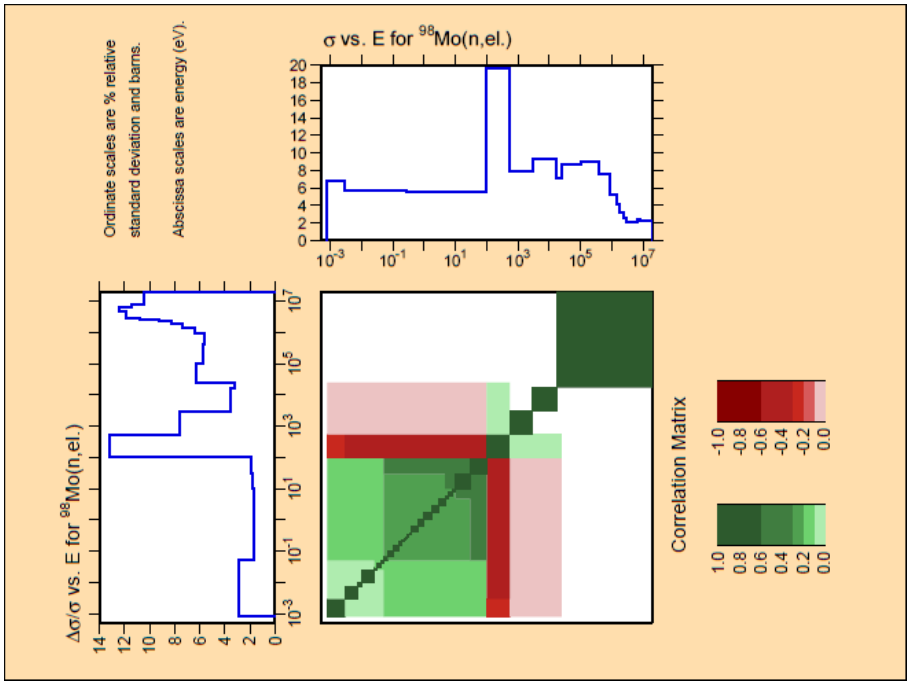

Figure C.74) ^{98}Mo CVDHCOV Elastic Scattering Covariance Data

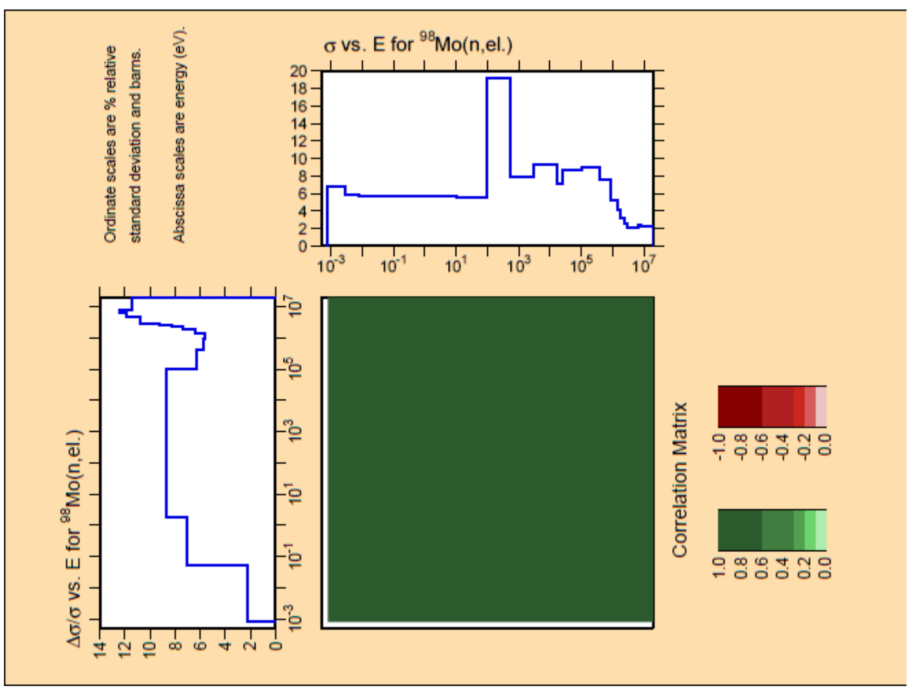

Figure C.75) ^{98}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

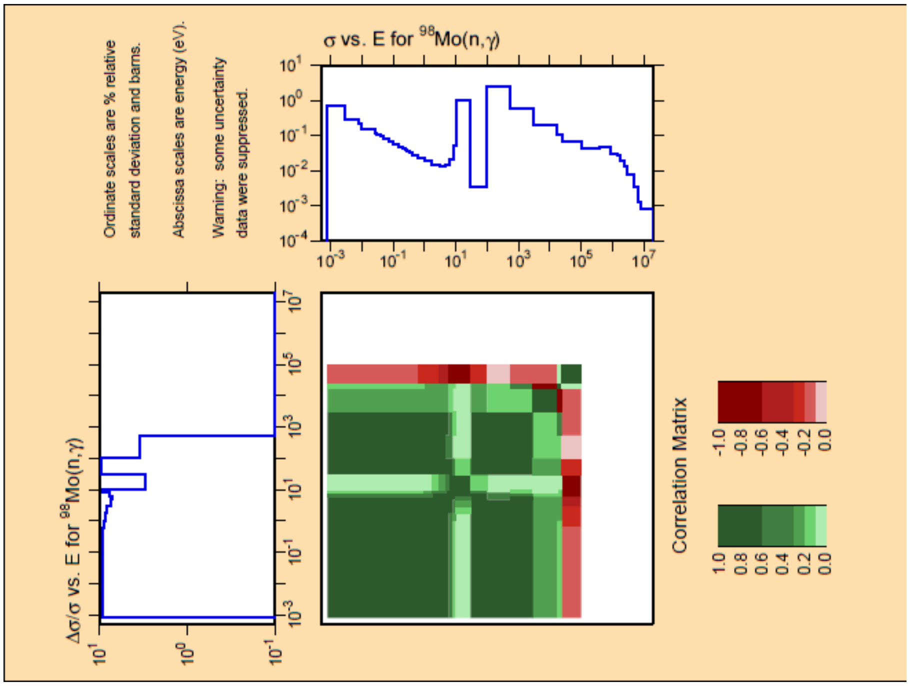

Figure C.76) ^{98}Mo Capture File 32 Covariance Data

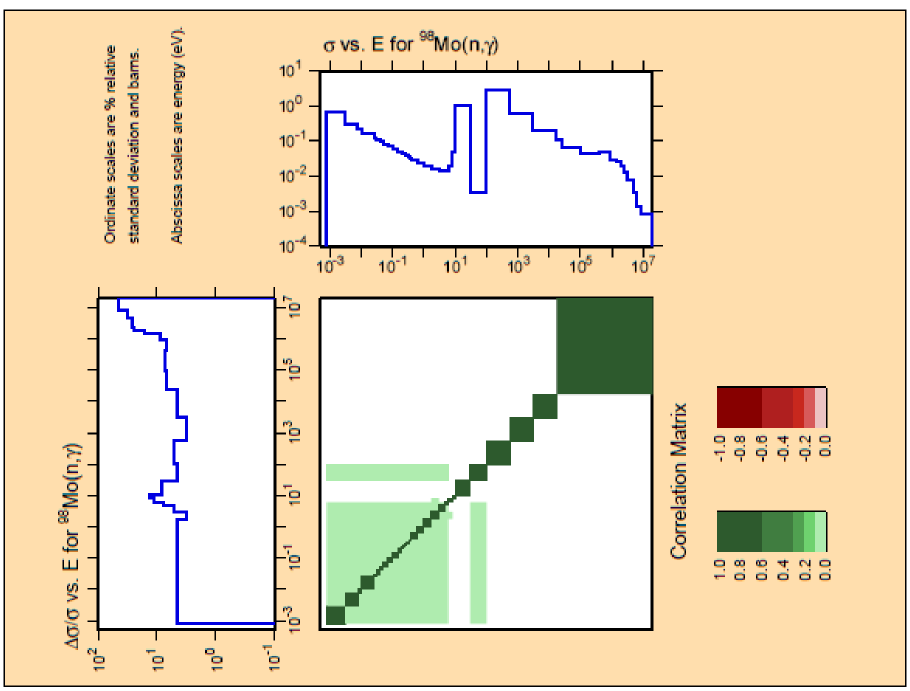

Figure C.77) ^{98}Mo Capture File 33 Covariance Data

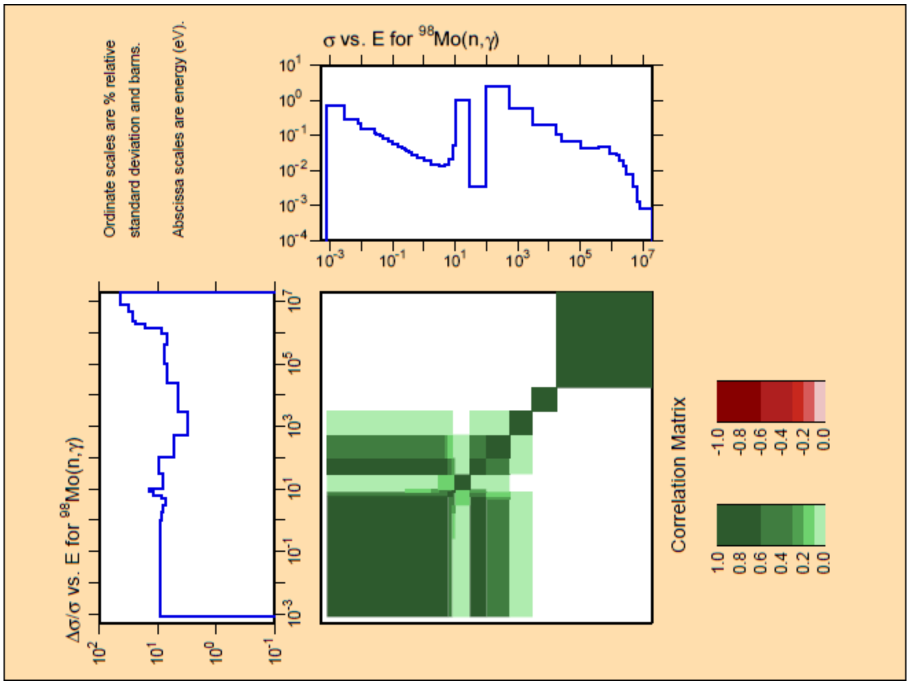

Figure C.78) ^{98}Mo CVDHCOV Capture Covariance Data

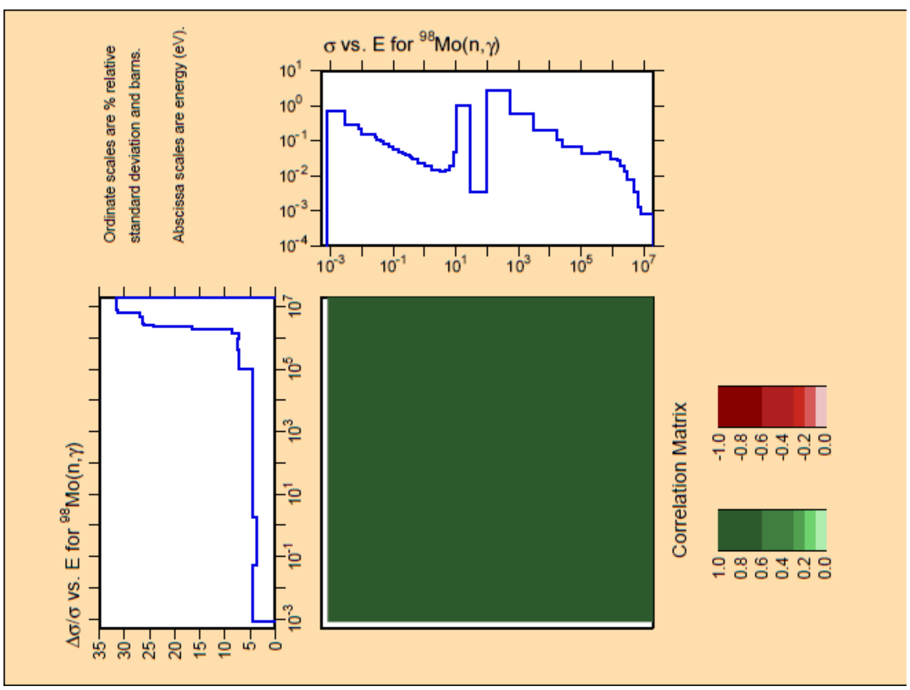

Figure C.79) ^{98}Mo LOFI Capture Covariance Data

^{100}Mo

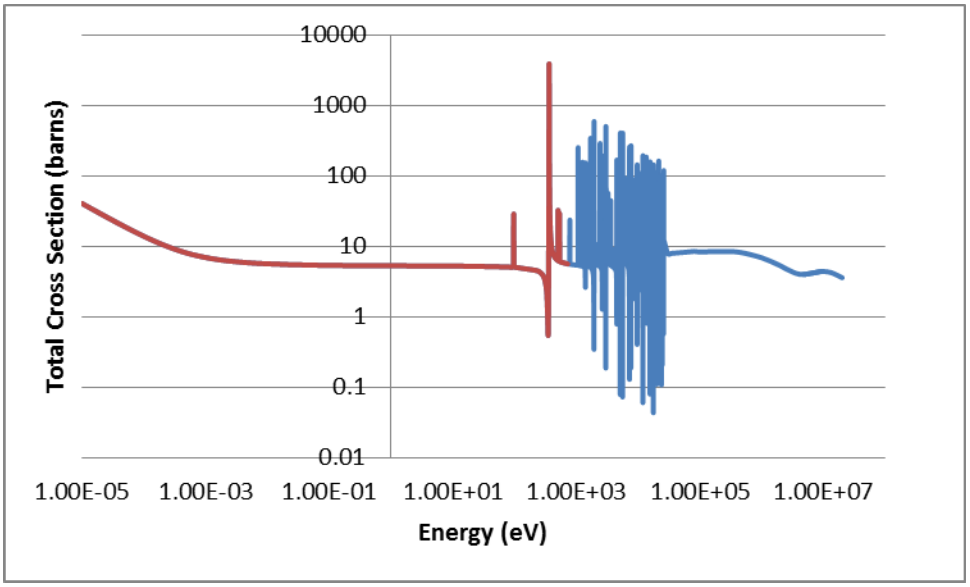

Figure C.80) ENDF/B-VII.1 ^{100}Mo Total Cross Section, 0-600 eV highlighted

Total Covariance Data

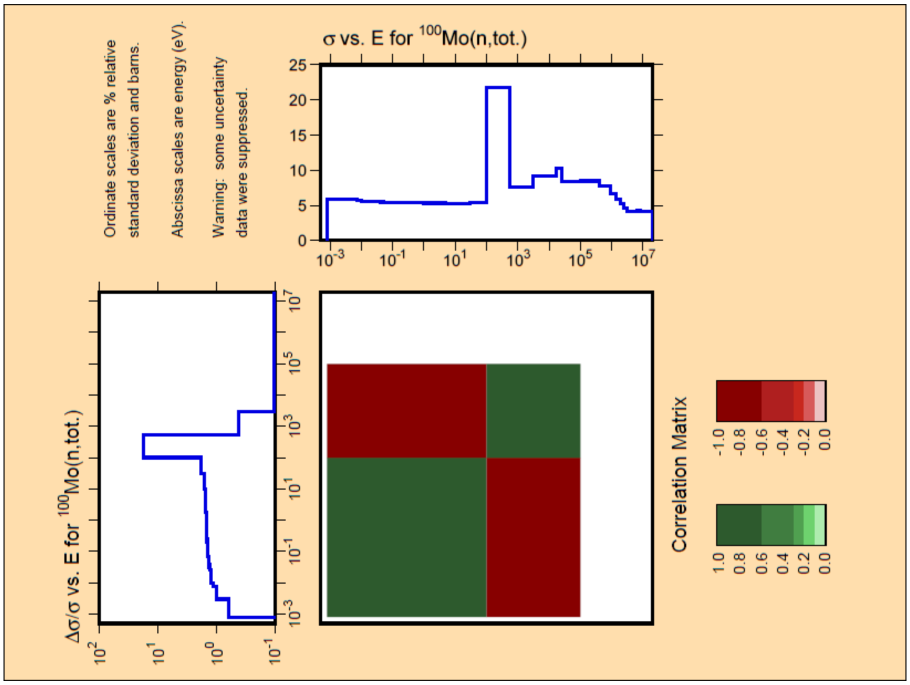

Figure C.81) ^{100}Mo Total File 32 Covariance Data

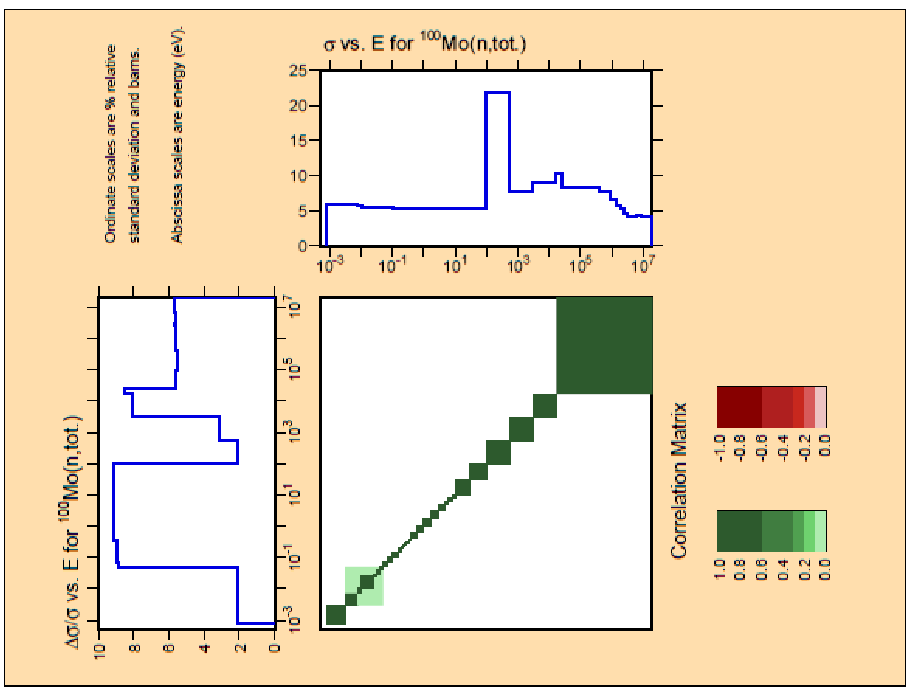

Figure C.82) ^{100}Mo Total File 33 Covariance Data

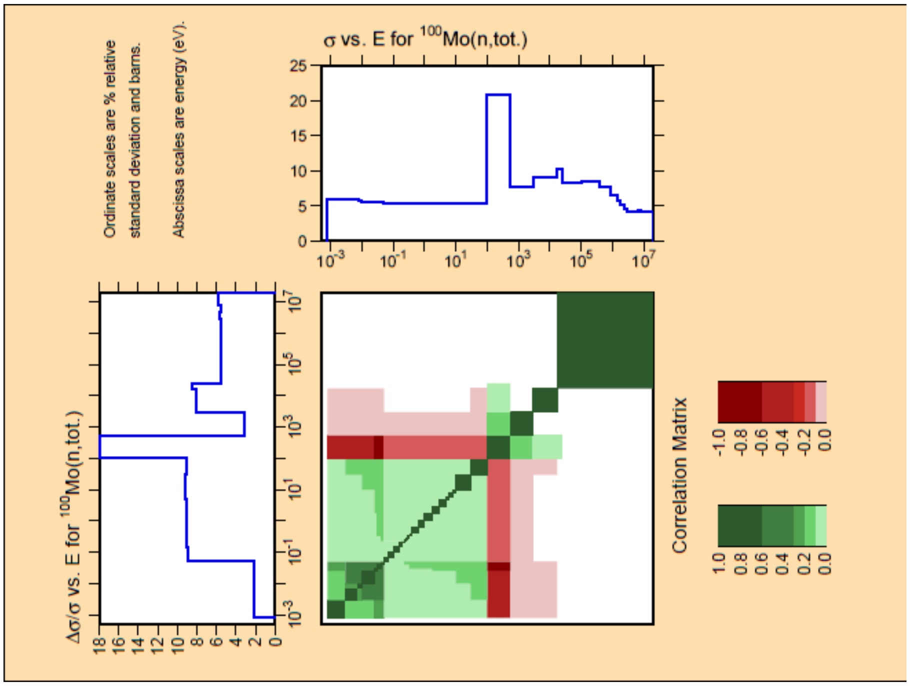

Figure C.83) ^{100}Mo CVDHCOV Total Covariance Data

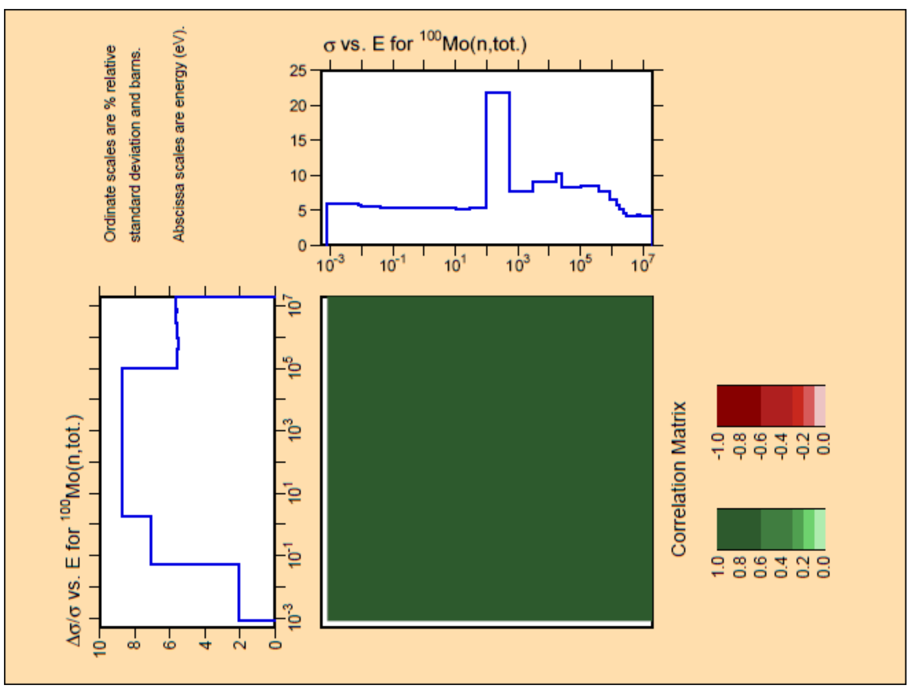

Figure C.84) ^{100}Mo LOFI Total Covariance Data

Elastic Scattering Covariance Data

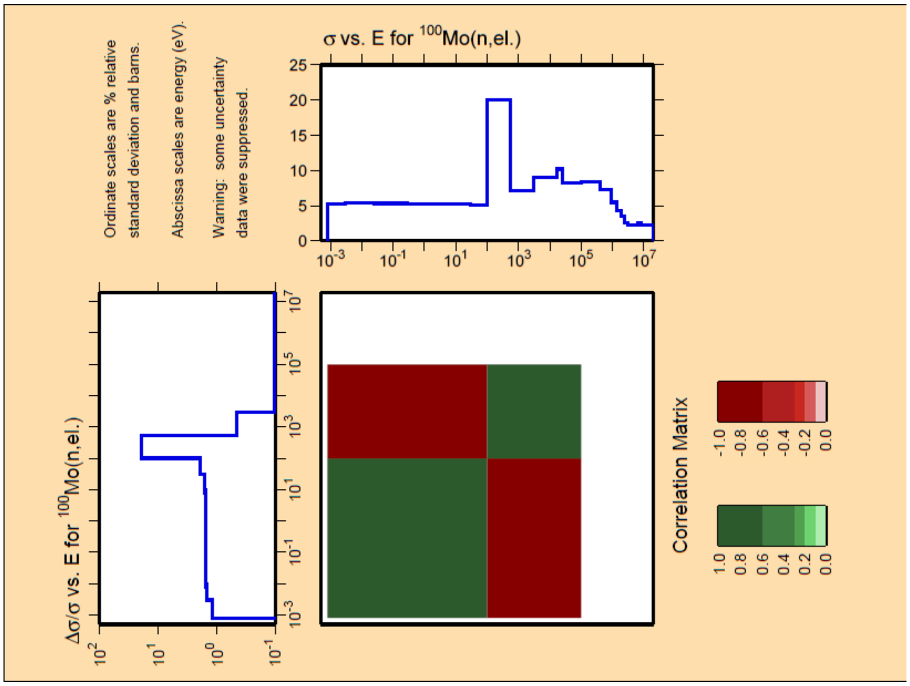

Figure C.85) ^{100}Mo Elastic Scattering File 32 Covariance Data

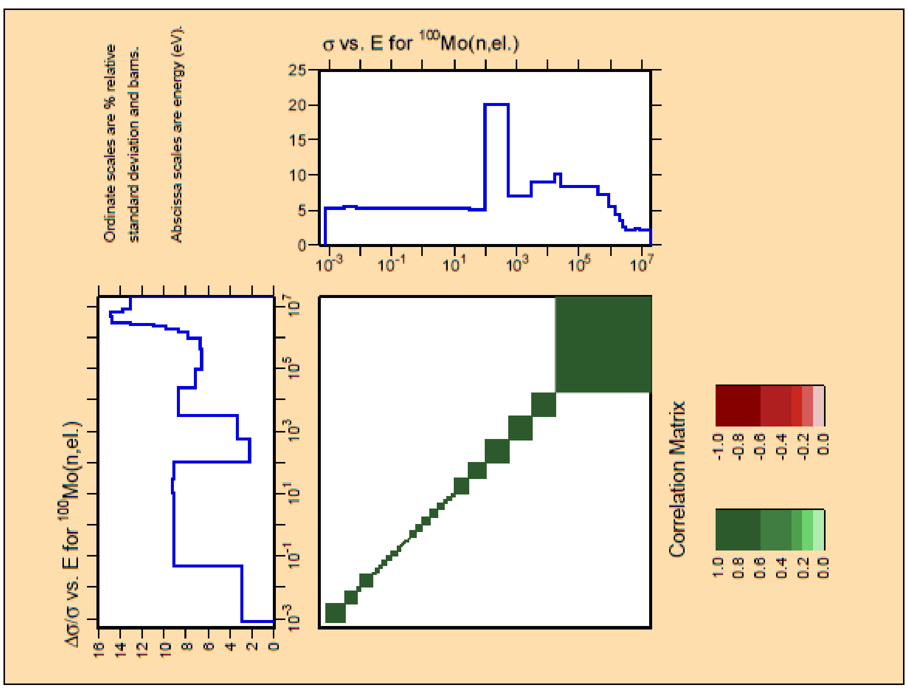

Figure C.86) ^{100}Mo Elastic Scattering File 33 Covariance Data

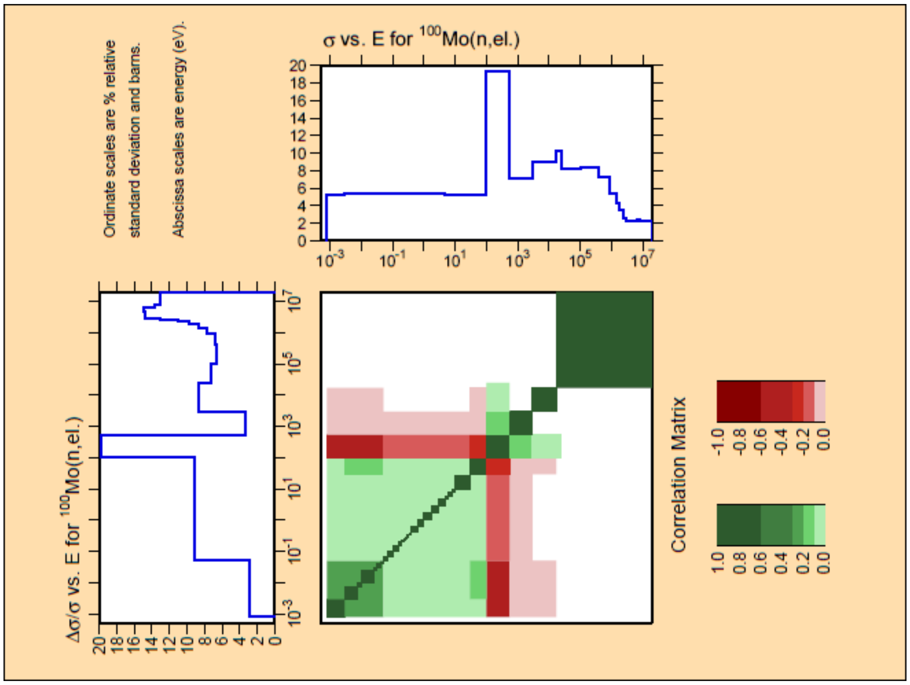

Figure C.87) ^{100}Mo CVDHCOV Elastic Scattering Covariance Data

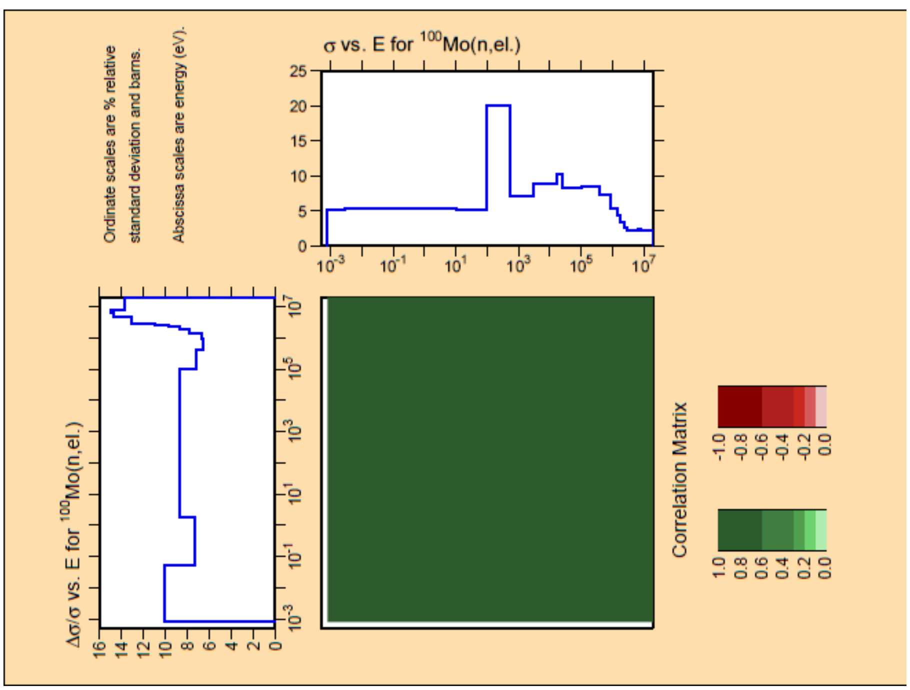

Figure C.88) ^{100}Mo LOFI Elastic Scattering Covariance Data

Capture Covariance Data

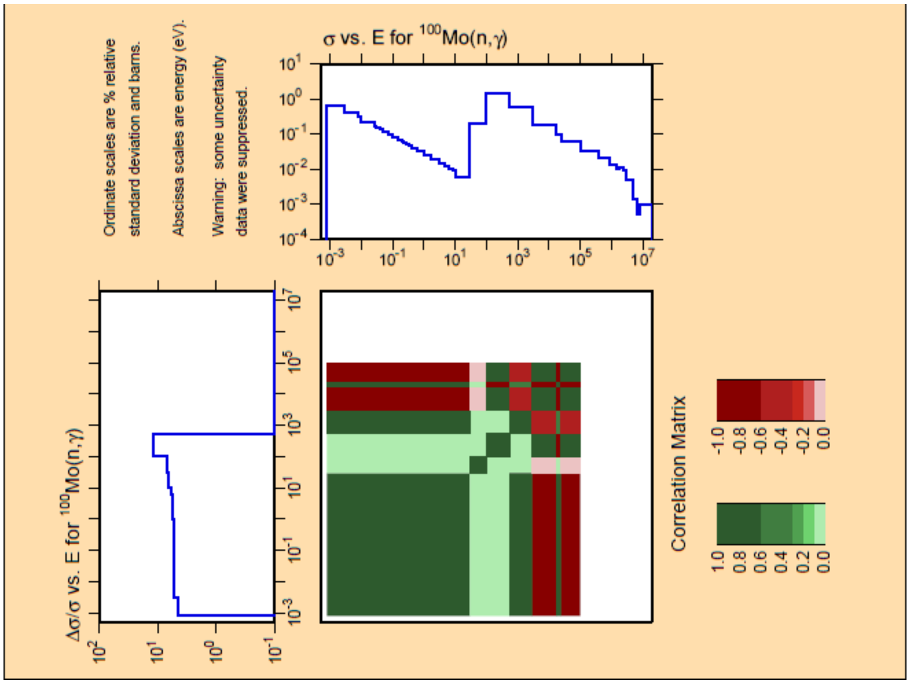

Figure C.89) ^{100}Mo Capture File 32 Covariance Data

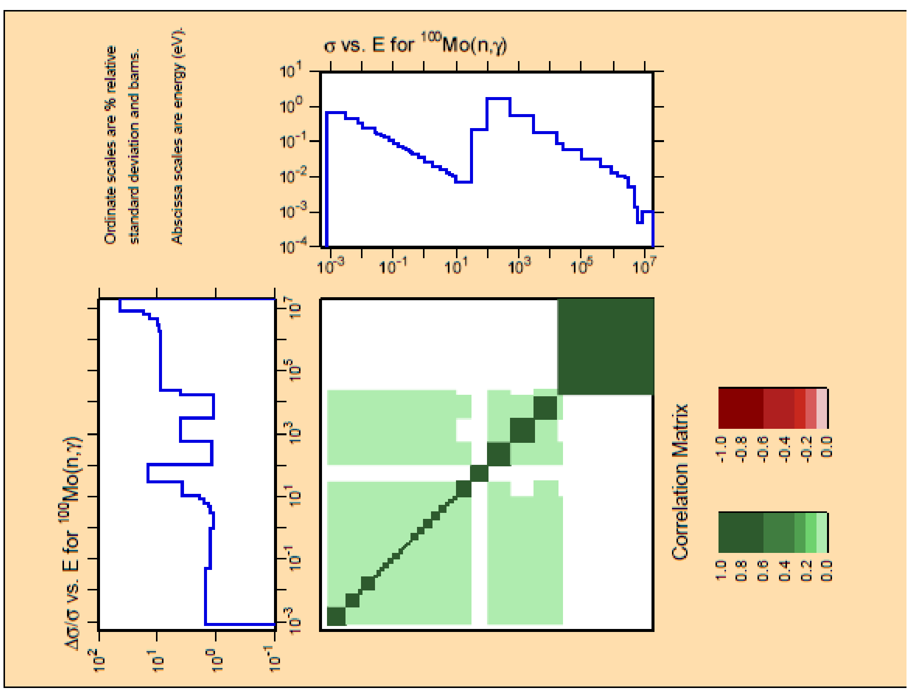

Figure C.90) ^{100}Mo Capture File 33 Covariance Data

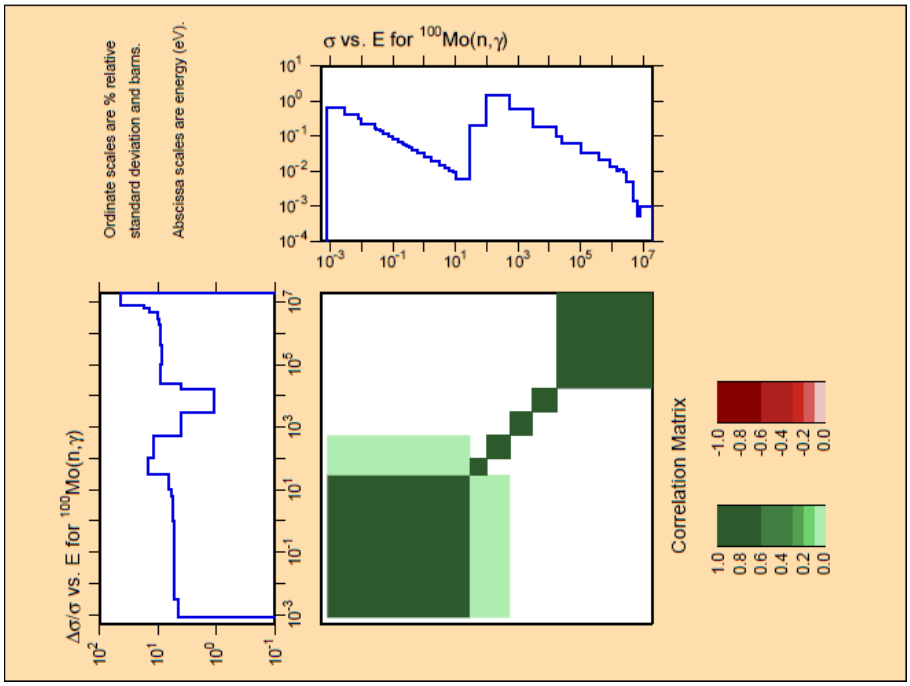

Figure C.91) ^{100}Mo CVDHCOV Capture Covariance Data

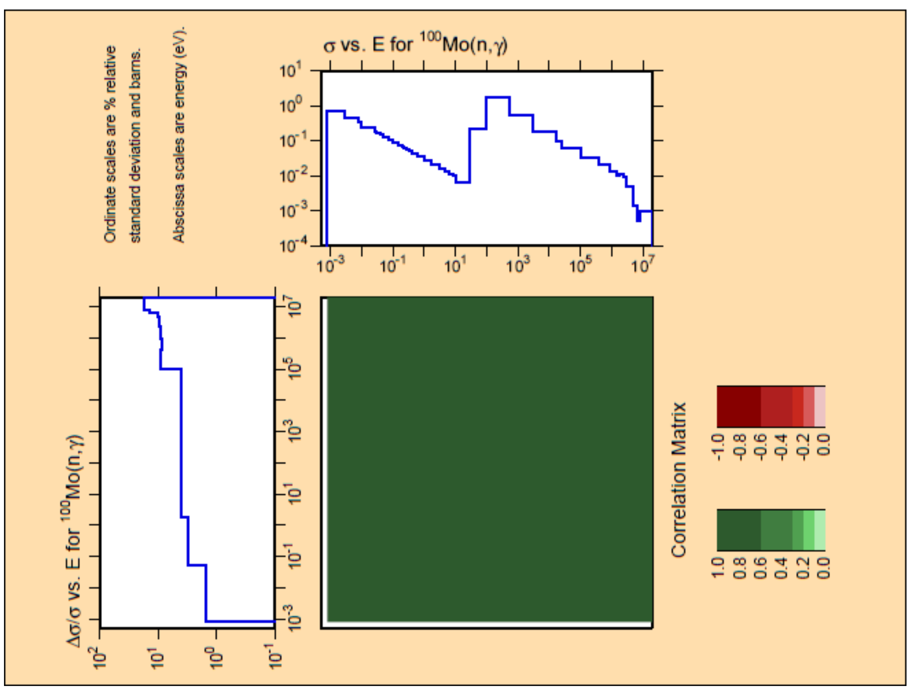

Figure C.92) ^{100}Mo LOFI Capture Covariance Data

Appendix D: ENDF Listing for JENDL 4.0 with RPI Resonance Parameters and High Fidelity Covariance Data

^{92}Mo

Resonance Parameters

```
                                                                   4225 0  0     0
 4.209200+4 9.111729+1          0          0          1          04225 2151     1
 4.209200+4 1.000000+0          0          0          2          04225 2151     2
 1.000000-5 5.000000+4          1          2          0          04225 2151     3
 0.000000+0 7.000000-1          0          0          2          04225 2151     4
 9.111729+1 0.000000+0          0          0        120        204225 2151     5
-2.450000+3 5.000000-1 1.332000+1 1.310000+1 2.200000-1 0.000000+04225 2151     6
 346.870000       0.5  3.116000-1 7.600000-3 3.040000-1 0.000000+04225 2151     7
 3.175000+3 5.000000-1 8.016000+0 7.800000+0 2.160000-1 0.000000+04225 2151     8
 6.817000+3 5.000000-1 7.580000-1 5.800000-1 1.780000-1 0.000000+04225 2151     9
 7.135000+3 5.000000-1 7.010000-1 5.200000-1 1.810000-1 0.000000+04225 2151    10
 1.154300+4 5.000000-1 1.115700+1 1.100000+1 1.570000-1 0.000000+04225 2151    11
 1.376000+4 5.000000-1 3.211600+1 3.200000+1 1.160000-1 0.000000+04225 2151    12
 1.655000+4 5.000000-1 6.265100+1 6.250000+1 1.510000-1 0.000000+04225 2151    13
 2.034500+4 5.000000-1 6.760000-1 4.900000-1 1.860000-1 0.000000+04225 2151    14
 2.109000+4 5.000000-1 3.116800+1 3.100000+1 1.680000-1 0.000000+04225 2151    15
 2.583000+4 5.000000-1 3.667500+1 3.650000+1 1.750000-1 0.000000+04225 2151    16
 2.855000+4 5.000000-1 5.050000-1 4.500000-1 5.500000-2 0.000000+04225 2151    17
 2.984000+4 5.000000-1 3.717400+1 3.700000+1 1.740000-1 0.000000+04225 2151    18
 3.113000+4 5.000000-1 5.727100+1 5.700000+1 2.710000-1 0.000000+04225 2151    19
 3.122000+4 5.000000-1 2.010550+1 2.000000+1 1.055000-1 0.000000+04225 2151    20
 3.349000+4 5.000000-1 5.910000-1 5.000000-1 9.100000-2 0.000000+04225 2151    21
 3.467000+4 5.000000-1 5.158000+0 5.000000+0 1.580000-1 0.000000+04225 2151    22
 3.574000+4 5.000000-1 2.670000+0 2.470000+0 2.000000-1 0.000000+04225 2151    23
 3.771000+4 5.000000-1 3.014900+1 3.000000+1 1.490000-1 0.000000+04225 2151    24
 4.793000+4 5.000000-1 5.011300+1 5.000000+1 1.130000-1 0.000000+04225 2151    25
 9.111729+1 0.000000+0          1          0        348        584225 2151    26
 1864.80000       1.5  4.470000-1 2.200000-2 4.250000-1 0.000000+04225 2151    27
 2.320000+3 1.500000+0 4.544000-1 2.940000-2 4.250000-1 0.000000+04225 2151    28
 3.061000+3 5.000000-1 2.900000-1 6.800000-2 2.220000-1 0.000000+04225 2151    29
 4.294000+3 1.500000+0 7.560000-1 5.250000-1 2.310000-1 0.000000+04225 2151    30
 5.579000+3 1.500000+0 5.810000-1 2.500000-1 3.310000-1 0.000000+04225 2151    31
 6.032000+3 1.500000+0 6.260000-1 2.900000-1 3.360000-1 0.000000+04225 2151    32
 6.484000+3 5.000000-1 1.212000+0 1.100000+0 1.120000-1 0.000000+04225 2151    33
 8.806000+3 1.500000+0 1.434000+0 1.250000+0 1.840000-1 0.000000+04225 2151    34
 8.918000+3 5.000000-1 3.740000+0 3.500000+0 2.400000-1 0.000000+04225 2151    35
 9.140000+3 5.000000-1 1.830000+0 1.600000+0 2.300000-1 0.000000+04225 2151    36
 1.059000+4 1.500000+0 6.060000-1 2.300000-1 3.760000-1 0.000000+04225 2151    37
 1.111800+4 1.500000+0 3.830000-1 1.800000-1 2.030000-1 0.000000+04225 2151    38
 1.285500+4 1.500000+0 8.720000-1 1.100000-1 7.620000-1 0.000000+04225 2151    39
 1.414500+4 5.000000-1 5.367000+0 5.200000+0 1.670000-1 0.000000+04225 2151    40
 1.446000+4 1.500000+0 3.430000-1 1.100000-1 2.330000-1 0.000000+04225 2151    41
 1.568000+4 5.000000-1 6.186000+0 6.000000+0 1.860000-1 0.000000+04225 2151    42
 1.571500+4 1.500000+0 1.135000+0 9.500000-1 1.850000-1 0.000000+04225 2151    43
 1.729500+4 1.500000+0 3.760000-1 1.250000-1 2.510000-1 0.000000+04225 2151    44
 1.803000+4 1.500000+0 5.680000-1 4.000000-1 1.680000-1 0.000000+04225 2151    45
 1.815500+4 5.000000-1 4.216000+0 4.000000+0 2.160000-1 0.000000+04225 2151    46
 1.919500+4 1.500000+0 3.195000+0 3.000000+0 1.950000-1 0.000000+04225 2151    47
 2.057000+4 5.000000-1 6.540000-1 5.000000-1 1.540000-1 0.000000+04225 2151    48
 2.065500+4 1.500000+0 5.680000-1 7.000000-2 4.980000-1 0.000000+04225 2151    49
 2.120000+4 5.000000-1 4.527000-1 2.770000-2 4.250000-1 0.000000+04225 2151    50
 2.177500+4 1.500000+0 6.230000-1 1.980000-1 4.250000-1 0.000000+04225 2151    51
 2.395500+4 1.500000+0 8.008000+0 7.600000+0 4.080000-1 0.000000+04225 2151    52
 2.547500+4 1.500000+0 4.372000+0 4.200000+0 1.720000-1 0.000000+04225 2151    53
 2.623000+4 5.000000-1 7.458100+1 7.300000+1 1.581000+0 0.000000+04225 2151    54
 2.804500+4 1.500000+0 6.872000+0 6.500000+0 3.720000-1 0.000000+04225 2151    55
```

```
2.871000+4 5.000000-1 2.624500+1 2.600000+1 2.450000-1 0.000000+04225 2151   56
3.008000+4 1.500000+0 7.440000-1 3.150000-1 4.290000-1 0.000000+04225 2151   57
3.034000+4 5.000000-1 5.734000+0 5.600000+0 1.340000-1 0.000000+04225 2151   58
3.259000+4 1.500000+0 1.796800+1 1.740000+1 5.680000-1 0.000000+04225 2151   59
3.446000+4 1.500000+0 5.648000+0 5.500000+0 1.480000-1 0.000000+04225 2151   60
3.483000+4 1.500000+0 5.268000+0 5.000000+0 2.680000-1 0.000000+04225 2151   61
3.560000+4 5.000000-1 1.211000+0 1.000000+0 2.110000-1 0.000000+04225 2151   62
3.600000+4 5.000000-1 9.250000-1 5.000000-1 4.250000-1 0.000000+04225 2151   63
3.648000+4 1.500000+0 2.112400+1 2.060000+1 5.240000-1 0.000000+04225 2151   64
3.706000+4 1.500000+0 1.239000+0 1.000000+0 2.390000-1 0.000000+04225 2151   65
3.797000+4 5.000000-1 8.810000-1 4.560000-1 4.250000-1 0.000000+04225 2151   66
3.846500+4 1.500000+0 2.730000+0 2.000000+0 7.300000-1 0.000000+04225 2151   67
3.912000+4 5.000000-1 3.222000+0 3.000000+0 2.220000-1 0.000000+04225 2151   68
4.022000+4 1.500000+0 7.922000+0 7.500000+0 4.220000-1 0.000000+04225 2151   69
4.036000+4 1.500000+0 3.727300+1 3.700000+1 2.730000-1 0.000000+04225 2151   70
4.215000+4 5.000000-1 5.720000-1 1.470000-1 4.250000-1 0.000000+04225 2151   71
4.244000+4 1.500000+0 7.550000-1 3.300000-1 4.250000-1 0.000000+04225 2151   72
4.336000+4 1.500000+0 5.310000-1 1.060000-1 4.250000-1 0.000000+04225 2151   73
4.409000+4 1.500000+0 6.530000-1 2.280000-1 4.250000-1 0.000000+04225 2151   74
4.470000+4 1.500000+0 5.750000-1 1.500000-1 4.250000-1 0.000000+04225 2151   75
4.501000+4 5.000000-1 7.370000-1 3.120000-1 4.250000-1 0.000000+04225 2151   76
4.535000+4 5.000000-1 7.890000-1 3.640000-1 4.250000-1 0.000000+04225 2151   77
4.626000+4 1.500000+0 4.450000+0 4.000000+0 4.500000-1 0.000000+04225 2151   78
4.661000+4 1.500000+0 7.350000-1 3.100000-1 4.250000-1 0.000000+04225 2151   79
4.715000+4 5.000000-1 8.680000-1 4.430000-1 4.250000-1 0.000000+04225 2151   80
4.771000+4 1.500000+0 1.065000+0 6.400000-1 4.250000-1 0.000000+04225 2151   81
4.877000+4 5.000000-1 9.550000-1 5.300000-1 4.250000-1 0.000000+04225 2151   82
4.997000+4 5.000000-1 1.185000+0 7.600000-1 4.250000-1 0.000000+04225 2151   83
5.018000+4 1.500000+0 3.575000+0 3.150000+0 4.250000-1 0.000000+04225 2151   84
5.000000+4 1.000000+6          2          2          0          04225 2151   85
0.000000+0 6.663200-1          1          0          3          04225 2151   86
9.111729+1 0.000000+0          0          0          1          04225 2151   87
5.000000-1 0.000000+0          5          0         96        154225 2151   88
0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04225 2151   89
5.000000+4 2.518200+3 0.000000+0 1.933900-1 1.550000-1 0.000000+04225 2151   90
6.000000+4 2.516700+3 0.000000+0 1.932800-1 1.550000-1 0.000000+04225 2151   91
7.000000+4 2.504400+3 0.000000+0 1.923400-1 1.550000-1 0.000000+04225 2151   92
8.000000+4 2.485100+3 0.000000+0 1.908600-1 1.550000-1 0.000000+04225 2151   93
9.000000+4 2.475600+3 0.000000+0 1.901300-1 1.550000-1 0.000000+04225 2151   94
1.000000+5 2.386600+3 0.000000+0 1.832900-1 1.550000-1 0.000000+04225 2151   95
2.000000+5 1.861200+3 0.000000+0 1.429400-1 1.550000-1 0.000000+04225 2151   96
3.000000+5 1.396000+3 0.000000+0 1.072200-1 1.550000-1 0.000000+04225 2151   97
4.000000+5 1.079700+3 0.000000+0 8.292000-2 1.550000-1 0.000000+04225 2151   98
5.000000+5 8.768200+2 0.000000+0 6.734000-2 1.550000-1 0.000000+04225 2151   99
6.000000+5 7.181900+2 0.000000+0 5.515700-2 1.550000-1 0.000000+04225 2151  100
7.000000+5 6.074500+2 0.000000+0 4.665200-2 1.550000-1 0.000000+04225 2151  101
8.000000+5 5.166200+2 0.000000+0 3.967600-2 1.550000-1 0.000000+04225 2151  102
9.000000+5 4.461800+2 0.000000+0 3.426600-2 1.550000-1 0.000000+04225 2151  103
1.000000+6 3.818300+2 0.000000+0 2.932400-2 1.550000-1 0.000000+04225 2151  104
9.111729+1 0.000000+0          1          0          2          04225 2151  105
5.000000-1 0.000000+0          5          0         96        154225 2151  106
0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04225 2151  107
5.000000+4 2.518200+3 0.000000+0 1.226300+0 2.400000-1 0.000000+04225 2151  108
6.000000+4 2.516700+3 0.000000+0 1.225600+0 2.400000-1 0.000000+04225 2151  109
7.000000+4 2.504400+3 0.000000+0 1.219600+0 2.400000-1 0.000000+04225 2151  110
8.000000+4 2.485100+3 0.000000+0 1.210200+0 2.400000-1 0.000000+04225 2151  111
9.000000+4 2.475600+3 0.000000+0 1.205600+0 2.400000-1 0.000000+04225 2151  112
1.000000+5 2.386600+3 0.000000+0 1.162300+0 2.400000-1 0.000000+04225 2151  113
2.000000+5 1.861200+3 0.000000+0 9.064100-1 2.400000-1 0.000000+04225 2151  114
3.000000+5 1.396000+3 0.000000+0 6.798700-1 2.400000-1 0.000000+04225 2151  115
4.000000+5 1.079700+3 0.000000+0 5.258100-1 2.400000-1 0.000000+04225 2151  116
5.000000+5 8.768200+2 0.000000+0 4.270100-1 2.400000-1 0.000000+04225 2151  117
6.000000+5 7.181900+2 0.000000+0 3.497600-1 2.400000-1 0.000000+04225 2151  118
7.000000+5 6.074500+2 0.000000+0 2.958300-1 2.400000-1 0.000000+04225 2151  119
8.000000+5 5.166200+2 0.000000+0 2.515900-1 2.400000-1 0.000000+04225 2151  120
9.000000+5 4.461800+2 0.000000+0 2.172900-1 2.400000-1 0.000000+04225 2151  121
```

```
 1.000000+6 3.818300+2 0.000000+0 1.859500-1 2.400000-1 0.000000+04225 2151  122
 1.500000+0 0.000000+0          5          0         96         154225 2151  123
 0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04225 2151  124
 5.000000+4 1.259100+3 0.000000+0 6.131700-1 2.400000-1 0.000000+04225 2151  125
 6.000000+4 1.258400+3 0.000000+0 6.128200-1 2.400000-1 0.000000+04225 2151  126
 7.000000+4 1.252200+3 0.000000+0 6.098200-1 2.400000-1 0.000000+04225 2151  127
 8.000000+4 1.242600+3 0.000000+0 6.051200-1 2.400000-1 0.000000+04225 2151  128
 9.000000+4 1.237800+3 0.000000+0 6.028100-1 2.400000-1 0.000000+04225 2151  129
 1.000000+5 1.193300+3 0.000000+0 5.811300-1 2.400000-1 0.000000+04225 2151  130
 2.000000+5 9.306000+2 0.000000+0 4.532000-1 2.400000-1 0.000000+04225 2151  131
 3.000000+5 6.980200+2 0.000000+0 3.399300-1 2.400000-1 0.000000+04225 2151  132
 4.000000+5 5.398400+2 0.000000+0 2.629000-1 2.400000-1 0.000000+04225 2151  133
 5.000000+5 4.384100+2 0.000000+0 2.135100-1 2.400000-1 0.000000+04225 2151  134
 6.000000+5 3.591000+2 0.000000+0 1.748800-1 2.400000-1 0.000000+04225 2151  135
 7.000000+5 3.037200+2 0.000000+0 1.479100-1 2.400000-1 0.000000+04225 2151  136
 8.000000+5 2.583100+2 0.000000+0 1.258000-1 2.400000-1 0.000000+04225 2151  137
 9.000000+5 2.230900+2 0.000000+0 1.086400-1 2.400000-1 0.000000+04225 2151  138
 1.000000+6 1.909100+2 0.000000+0 9.297500-2 2.400000-1 0.000000+04225 2151  139
 9.111729+1 0.000000+0          2          0          2          04225 2151  140
 1.500000+0 0.000000+0          5          0         96         154225 2151  141
 0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04225 2151  142
 5.000000+4 1.259100+3 0.000000+0 1.259100-1 1.550000-1 0.000000+04225 2151  143
 6.000000+4 1.258400+3 0.000000+0 1.258400-1 1.550000-1 0.000000+04225 2151  144
 7.000000+4 1.252200+3 0.000000+0 1.252200-1 1.550000-1 0.000000+04225 2151  145
 8.000000+4 1.242600+3 0.000000+0 1.242600-1 1.550000-1 0.000000+04225 2151  146
 9.000000+4 1.237800+3 0.000000+0 1.237800-1 1.550000-1 0.000000+04225 2151  147
 1.000000+5 1.193300+3 0.000000+0 1.193300-1 1.550000-1 0.000000+04225 2151  148
 2.000000+5 9.306000+2 0.000000+0 9.306000-2 1.550000-1 0.000000+04225 2151  149
 3.000000+5 6.980200+2 0.000000+0 6.980200-2 1.550000-1 0.000000+04225 2151  150
 4.000000+5 5.398400+2 0.000000+0 5.398400-2 1.550000-1 0.000000+04225 2151  151
 5.000000+5 4.384100+2 0.000000+0 4.384100-2 1.550000-1 0.000000+04225 2151  152
 6.000000+5 3.591000+2 0.000000+0 3.591000-2 1.550000-1 0.000000+04225 2151  153
 7.000000+5 3.037200+2 0.000000+0 3.037200-2 1.550000-1 0.000000+04225 2151  154
 8.000000+5 2.583100+2 0.000000+0 2.583100-2 1.550000-1 0.000000+04225 2151  155
 9.000000+5 2.230900+2 0.000000+0 2.230900-2 1.550000-1 0.000000+04225 2151  156
 1.000000+6 1.909100+2 0.000000+0 1.909100-2 1.550000-1 0.000000+04225 2151  157
 2.500000+0 0.000000+0          5          0         96         154225 2151  158
 0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04225 2151  159
 5.000000+4 8.393900+2 0.000000+0 8.393900-2 1.550000-1 0.000000+04225 2151  160
 6.000000+4 8.389100+2 0.000000+0 8.389100-2 1.550000-1 0.000000+04225 2151  161
 7.000000+4 8.348000+2 0.000000+0 8.348000-2 1.550000-1 0.000000+04225 2151  162
 8.000000+4 8.283700+2 0.000000+0 8.283700-2 1.550000-1 0.000000+04225 2151  163
 9.000000+4 8.252000+2 0.000000+0 8.252000-2 1.550000-1 0.000000+04225 2151  164
 1.000000+5 7.955200+2 0.000000+0 7.955200-2 1.550000-1 0.000000+04225 2151  165
 2.000000+5 6.204000+2 0.000000+0 6.204000-2 1.550000-1 0.000000+04225 2151  166
 3.000000+5 4.653400+2 0.000000+0 4.653400-2 1.550000-1 0.000000+04225 2151  167
 4.000000+5 3.599000+2 0.000000+0 3.599000-2 1.550000-1 0.000000+04225 2151  168
 5.000000+5 2.922700+2 0.000000+0 2.922700-2 1.550000-1 0.000000+04225 2151  169
 6.000000+5 2.394000+2 0.000000+0 2.394000-2 1.550000-1 0.000000+04225 2151  170
 7.000000+5 2.024800+2 0.000000+0 2.024800-2 1.550000-1 0.000000+04225 2151  171
 8.000000+5 1.722100+2 0.000000+0 1.722100-2 1.550000-1 0.000000+04225 2151  172
 9.000000+5 1.487300+2 0.000000+0 1.487300-2 1.550000-1 0.000000+04225 2151  173
 1.000000+6 1.272800+2 0.000000+0 1.272800-2 1.550000-1 0.000000+04225 2151  174
                                                                  4225 2  099999
```

Covariance Data

```
 0.000000+0 0.000000+0          0          0          0          04225 0  0    0
  42092.0   9.111729+1          0          0          1          0422532151    1
  42092.0   1.000000+0          0          0          1          0422532151    2
 5.100000-4 4.000000+4          1          2          0          1422532151    3
     0.0    7.000000-1          0          1          0          0422532151    4
 9.111729+1                     0          0          1          0422532151    5
                                3          0         33          2422532151    6
346.8700000      0.5   3.116000-1 7.600000-3 3.040000-1           422532151    7
1864.800000      1.5   4.470000-1 2.200000-2 4.250000-1           422532151    8
```

```
 5.329007-3 2.565975-6 3.452439-4 6.512053-8-6.41219-10-2.893094-9422532151    9
 7.435820-7 1.076692-4 4.107240-9-2.77129-10-7.65711-10 3.354735-2422532151   10
-5.765957-6-7.719465-8-9.565235-9 1.089142+1 9.644258-4-1.580376-3422532151   11
 1.174366-4 1.967030-4 1.802432-1                                 422532151   12
       0.0        0.0          0          0          0          0422532  0   13
       0.0        0.0          0          0          0          04225 0  0   14
 4.209200+4 9.111730+1          0          0          0          1422533  1    1
 0.000000+0 0.000000+0          0          1          0          1422533  1    2
 0.000000+0 0.000000+0          1          5       1035         45422533  1    3
 1.000000-5 3.000000-3 7.500000-3 1.000000-2 2.530000-2 3.000000-2422533  1    4
 4.000000-2 5.000000-2 7.000000-2 1.000000-1 1.500000-1 2.000000-1422533  1    5
 2.250000-1 2.500000-1 2.750000-1 3.250000-1 3.500000-1 3.750000-1422533  1    6
 4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0422533  1    7
 6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2422533  1    8
 3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5422533  1    9
 1.400000+6 1.850000+6 2.354000+6 2.479000+6 3.000000+6 4.800000+6422533  1   10
 6.434000+6 8.187300+6 2.000000+7 5.271616-4 0.000000+0 0.000000+0422533  1   11
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   12
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   13
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   14
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   15
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   16
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   17
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 5.281264-4422533  1   18
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   21
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   22
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   23
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   24
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 5.284941-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   26
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   28
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   52
 5.289080-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   53
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   54
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   57
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 0.000000+0 0.000000+0 2.888955-3 0.000000+0 0.000000+0 0.000000+0422533  1   59
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1   60
```

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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  116
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  117
2.705456-3 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  118
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  119
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  120
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  124
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  125
0.000000+0 0.000000+0 0.000000+0 2.526570-3 0.000000+0 0.000000+0422533  1  126
```

```
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  127
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  132
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  133
0.000000+0 0.000000+0 2.041142-3 0.000000+0 0.000000+0 0.000000+0422533  1  134
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  137
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  139
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  147
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 2.971038-2422533  1  153
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  1  154
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1.145784-2 1.182062-2 1.203799-2 5.416960-3 4.048000-3 4.209920-3422533  1  163
4.666240-3 5.048960-3 5.107840-3 5.108944-3 4.990080-3 4.769280-3422533  1  164
4.651520-3 4.798794-3 4.887040-3 3.025000-3 3.146000-3 3.487000-3422533  1  165
3.773000-3 3.817000-3 3.817825-3 3.729000-3 3.564000-3 3.476000-3422533  1  166
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4.095360-3 4.225025-3 4.302720-3 3.994240-3 4.120703-3 4.196480-3422533  1  175
4.251170-3 4.329346-3 4.408960-3 0.000000+0 0.000000+0 0.000000+0422533  1  176
0.000000+0 0.000000+0          0          0          0          0422533  099999
4.209200+4 9.111730+1          0          0          0          1422533  2    1
0.000000+0 0.000000+0          0          2          0          1422533  2    2
0.000000+0 0.000000+0          1          5       1035         45422533  2    3
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2.250000-1 2.500000-1 2.750000-1 3.250000-1 3.500000-1 3.750000-1422533  2    6
4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0422533  2    7
6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2422533  2    8
3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5422533  2    9
1.400000+6 1.850000+6 2.354000+6 2.479000+6 3.000000+6 4.800000+6422533  2   10
6.434000+6 8.187300+6 2.000000+7 7.920284-4 0.000000+0 0.000000+0422533  2   11
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   12
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   14
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   15
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7.920284-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   26
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   27
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   28
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7.920284-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   33
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   34
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   35
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   36
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0.000000+0 0.000000+0 0.000000+0 7.920284-4 0.000000+0 0.000000+0422533  2   46
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   47
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   68
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   69
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   70
0.000000+0 0.000000+0 0.000000+0 2.908876-3 0.000000+0 0.000000+0422533  2   71
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   74
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   75
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   76
0.000000+0 0.000000+0 2.884549-3 0.000000+0 0.000000+0 0.000000+0422533  2   77
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   78
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   79
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   80
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   81
```

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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   84
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   86
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   87
0.000000+0 0.000000+0 0.000000+0 2.854337-3 0.000000+0 0.000000+0422533  2   88
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   89
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   90
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   91
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   92
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 2.842383-3422533  2   93
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   96
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2   97
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  132
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  136
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  137
1.823632-3 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  138
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  139
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  140
0.000000+0 0.000000+0 0.000000+0 1.608170-3 0.000000+0 0.000000+0422533  2  141
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  143
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 1.387116-3422533  2  144
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  145
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  146
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0422533  2  147
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2.632328-2 2.500529-2 2.526450-2 5.476000-3 4.913600-3 4.958000-3422533  2  163
5.032000-3 5.254000-3 6.216000-3 6.768484-3 8.362000-3 1.019720-2422533  2  164
1.067080-2 1.013652-2 1.024160-2 4.408960-3 4.448800-3 4.515200-3422533  2  165
4.714400-3 5.577600-3 6.073342-3 7.503200-3 9.149920-3 9.574880-3422533  2  166
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2.274000-2 2.404000-2 2.564000-2 2.762800-2 3.220000-2 3.430000-2422533102  162
3.808000-2 4.208900-2 4.648000-2 9.139360-3 9.139360-3 2.009512-2422533102  163
2.173944-2 2.298224-2 2.451184-2 2.641237-2 3.078320-2 3.279080-2422533102  164
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4.023708-2 4.443488-2 4.418404-2 4.779948-2 5.053208-2 5.389528-2422533102  167
5.807406-2 6.768440-2 7.209860-2 8.004416-2 8.847108-2 9.770096-2422533102  168
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7.740880-2 8.245720-2 9.154432-2 1.011820-1 1.117379-1 6.574096-2422533102  171
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7.633064-2 8.896216-2 9.476404-2 1.052074-1 1.162835-1 1.284149-1422533102  173
1.036840-1 1.104460-1 1.226176-1 1.355266-1 1.496656-1 1.176490-1422533102  174
1.306144-1 1.443653-1 1.594264-1 1.450086-1 1.602749-1 1.769958-1422533102  175
1.771484-1 1.956297-1 2.160390-1 0.000000+0 0.000000+0 0.000000+0422533102  176
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Resonance Parameters

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 4.209400+4 1.000000+0          0          0          2          04231 2151     2
 1.000000-5 2.000000+4          1          2          0          04231 2151     3
 0.000000+0 6.900000-1          0          0          2          04231 2151     4
 9.309840+1 0.000000+0          0          0         84        144231 2151     5
-1.430000+2 5.000000-1 2.770000-1 1.490000-1 1.280000-1 0.000000+04231 2151     6
 1542.40000       0.5  1.560000+0 1.420000+0 1.400000-1 0.000000+04231 2151     7
 3.602000+3 5.000000-1 2.637000+0 2.500000+0 1.370000-1 0.000000+04231 2151     8
 4.622000+3 5.000000-1 6.890000-1 5.260000-1 1.630000-1 0.000000+04231 2151     9
 5.433000+3 5.000000-1 1.541400+1 1.530000+1 1.140000-1 0.000000+04231 2151    10
 6.718000+3 5.000000-1 1.131000+0 1.000000+0 1.310000-1 0.000000+04231 2151    11
 7.865000+3 5.000000-1 1.116000+0 1.000000+0 1.160000-1 0.000000+04231 2151    12
 9.705000+3 5.000000-1 6.390000-1 5.000000-1 1.390000-1 0.000000+04231 2151    13
 1.075200+4 5.000000-1 2.509100+1 2.500000+1 9.100000-2 0.000000+04231 2151    14
 1.352500+4 5.000000-1 2.015100+1 2.000000+1 1.510000-1 0.000000+04231 2151    15
 1.570500+4 5.000000-1 2.360000+0 2.200000+0 1.600000-1 0.000000+04231 2151    16
 1.709500+4 5.000000-1 9.135000+0 9.000000+0 1.350000-1 0.000000+04231 2151    17
 1.815500+4 5.000000-1 2.020700+1 2.000000+1 2.070000-1 0.000000+04231 2151    18
 2.025500+4 5.000000-1 3.017700+1 3.000000+1 1.770000-1 0.000000+04231 2151    19
 9.309840+1 0.000000+0          1          0        270        454231 2151    20
 108.500000       0.5  1.881100-1 1.100000-4 1.880000-1 0.000000+04231 2151    21
 1051.30000       0.5  1.940000-1 6.000000-3 1.880000-1 0.000000+04231 2151    22
 1664.00000       1.5  1.940000-1 6.000000-3 1.880000-1 0.000000+04231 2151    23
 2.179200+3 1.500000+0 4.710000-1 2.960000-1 1.750000-1 0.000000+04231 2151    24
 3.163000+3 1.500000+0 3.020000-1 1.270000-1 1.750000-1 0.000000+04231 2151    25
 3.575000+3 1.500000+0 3.330000-1 1.580000-1 1.750000-1 0.000000+04231 2151    26
 4.368000+3 1.500000+0 4.147000+0 4.000000+0 1.470000-1 0.000000+04231 2151    27
 4.928000+3 5.000000-1 1.294000+0 1.090000+0 2.040000-1 0.000000+04231 2151    28
 5.135000+3 1.500000+0 1.669000+0 1.500000+0 1.690000-1 0.000000+04231 2151    29
 5.454000+3 5.000000-1 1.834000-1 8.400000-3 1.750000-1 0.000000+04231 2151    30
 5.953000+3 5.000000-1 2.840000-1 1.090000-1 1.750000-1 0.000000+04231 2151    31
 6.030000+3 5.000000-1 1.870000-1 1.200000-2 1.750000-1 0.000000+04231 2151    32
 6.407000+3 5.000000-1 1.750000-1 3.500000-2 1.400000-1 0.000000+04231 2151    33
 6.960000+3 5.000000-1 2.050000-1 3.500000-2 1.700000-1 0.000000+04231 2151    34
 7.128000+3 5.000000-1 1.845000-1 9.500000-3 1.750000-1 0.000000+04231 2151    35
 8.275000+3 1.500000+0 2.150000+0 2.000000+0 1.500000-1 0.000000+04231 2151    36
 8.608000+3 1.500000+0 7.300000-1 5.000000-1 2.300000-1 0.000000+04231 2151    37
 8.660000+3 5.000000-1 7.850000-1 6.100000-1 1.750000-1 0.000000+04231 2151    38
 9.590000+3 1.500000+0 6.840000-1 5.000000-1 1.840000-1 0.000000+04231 2151    39
 9.813000+3 1.500000+0 3.670000-1 1.920000-1 1.750000-1 0.000000+04231 2151    40
 1.022500+4 1.500000+0 3.168000+0 3.000000+0 1.680000-1 0.000000+04231 2151    41
 1.053500+4 1.500000+0 4.310000-1 2.560000-1 1.750000-1 0.000000+04231 2151    42
 1.077600+4 1.500000+0 6.805000+0 6.630000+0 1.750000-1 0.000000+04231 2151    43
 1.142000+4 1.500000+0 5.570000-1 3.820000-1 1.750000-1 0.000000+04231 2151    44
 1.181500+4 1.500000+0 1.975000+0 1.800000+0 1.750000-1 0.000000+04231 2151    45
 1.220500+4 1.500000+0 4.250000-1 2.500000-1 1.750000-1 0.000000+04231 2151    46
 1.228000+4 5.000000-1 4.790000-1 3.040000-1 1.750000-1 0.000000+04231 2151    47
 1.298000+4 5.000000-1 2.130000-1 3.800000-2 1.750000-1 0.000000+04231 2151    48
 1.341500+4 5.000000-1 6.810000-1 5.060000-1 1.750000-1 0.000000+04231 2151    49
 1.370500+4 1.500000+0 1.335000+0 1.160000+0 1.750000-1 0.000000+04231 2151    50
 1.399000+4 1.500000+0 3.800000+0 3.500000+0 3.000000-1 0.000000+04231 2151    51
 1.411000+4 5.000000-1 4.380000-1 2.630000-1 1.750000-1 0.000000+04231 2151    52
 1.534000+4 5.000000-1 3.980000-1 2.230000-1 1.750000-1 0.000000+04231 2151    53
 1.676500+4 5.000000-1 2.489999-1 7.399990-2 1.750000-1 0.000000+04231 2151    54
 1.732000+4 5.000000-1 6.380000-1 4.630000-1 1.750000-1 0.000000+04231 2151    55
 1.739000+4 5.000000-1 3.440000-1 1.690000-1 1.750000-1 0.000000+04231 2151    56
 1.752000+4 5.000000-1 2.240000-1 4.900000-2 1.750000-1 0.000000+04231 2151    57
 1.780500+4 1.500000+0 1.214000+0 1.000000+0 2.140000-1 0.000000+04231 2151    58
 1.833600+4 5.000000-1 6.960000-1 5.210000-1 1.750000-1 0.000000+04231 2151    59
 1.849500+4 1.500000+0 4.900000-1 3.150000-1 1.750000-1 0.000000+04231 2151    60
 1.887500+4 1.500000+0 1.203000+0 1.000000+0 2.030000-1 0.000000+04231 2151    61
 1.922500+4 1.500000+0 1.217000+0 1.000000+0 2.170000-1 0.000000+04231 2151    62
 1.970000+4 1.500000+0 3.650000-1 1.900000-1 1.750000-1 0.000000+04231 2151    63
```

```
2.007500+4 5.000000-1 5.780000-1 4.030000-1 1.750000-1 0.000000+04231 2151   64
2.067000+4 1.500000+0 1.205000+0 1.030000+0 1.750000-1 0.000000+04231 2151   65
2.000000+4 1.000000+6          2          2          0          04231 2151   66
0.000000+0 4.474100-1          1          0          3          04231 2151   67
9.309840+1 0.000000+0          0          0          1          04231 2151   68
5.000000-1 0.000000+0          5          0        114        184231 2151   69
0.000000+0 0.000000+0 2.000000+0 1.000000+0 0.000000+0 0.000000+04231 2151   70
2.000000+4 1.256600+3 0.000000+0 1.143500-1 1.280000-1 0.000000+04231 2151   71
3.000000+4 1.219300+3 0.000000+0 1.109600-1 1.280000-1 0.000000+04231 2151   72
4.000000+4 1.200100+3 0.000000+0 1.092100-1 1.280000-1 0.000000+04231 2151   73
5.000000+4 1.176800+3 0.000000+0 1.070900-1 1.280000-1 0.000000+04231 2151   74
6.000000+4 1.156000+3 0.000000+0 1.052000-1 1.280000-1 0.000000+04231 2151   75
7.000000+4 1.131400+3 0.000000+0 1.029600-1 1.280000-1 0.000000+04231 2151   76
8.000000+4 1.101000+3 0.000000+0 1.001900-1 1.280000-1 0.000000+04231 2151   77
9.000000+4 1.079800+3 0.000000+0 9.826300-2 1.280000-1 0.000000+04231 2151   78
1.000000+5 1.060400+3 0.000000+0 9.649800-2 1.280000-1 0.000000+04231 2151   79
2.000000+5 8.498600+2 0.000000+0 7.733700-2 1.280000-1 0.000000+04231 2151   80
3.000000+5 6.518200+2 0.000000+0 5.931500-2 1.280000-1 0.000000+04231 2151   81
4.000000+5 5.087700+2 0.000000+0 4.629900-2 1.280000-1 0.000000+04231 2151   82
5.000000+5 4.121400+2 0.000000+0 3.750400-2 1.280000-1 0.000000+04231 2151   83
6.000000+5 3.355200+2 0.000000+0 3.053200-2 1.280000-1 0.000000+04231 2151   84
7.000000+5 2.817800+2 0.000000+0 2.564200-2 1.280000-1 0.000000+04231 2151   85
8.000000+5 2.368900+2 0.000000+0 2.155700-2 1.280000-1 0.000000+04231 2151   86
9.000000+5 2.074200+2 6.271400-4 1.887500-2 1.280000-1 0.000000+04231 2151   87
1.000000+6 2.104200+2 5.506000-2 1.914800-2 1.280000-1 0.000000+04231 2151   88
9.309840+1 0.000000+0          1          0          2          04231 2151   89
5.000000-1 0.000000+0          5          0        114        184231 2151   90
0.000000+0 0.000000+0 1.000000+0 1.000000+0 0.000000+0 0.000000+04231 2151   91
2.000000+4 1.256600+3 0.000000+0 9.085400-1 1.880000-1 0.000000+04231 2151   92
3.000000+4 1.219300+3 0.000000+0 8.815400-1 1.880000-1 0.000000+04231 2151   93
4.000000+4 1.200100+3 0.000000+0 8.676600-1 1.880000-1 0.000000+04231 2151   94
5.000000+4 1.176800+3 0.000000+0 8.508500-1 1.880000-1 0.000000+04231 2151   95
6.000000+4 1.156000+3 0.000000+0 8.358200-1 1.880000-1 0.000000+04231 2151   96
7.000000+4 1.131400+3 0.000000+0 8.179900-1 1.880000-1 0.000000+04231 2151   97
8.000000+4 1.101000+3 0.000000+0 7.959900-1 1.880000-1 0.000000+04231 2151   98
9.000000+4 1.079800+3 0.000000+0 7.807000-1 1.880000-1 0.000000+04231 2151   99
1.000000+5 1.060400+3 0.000000+0 7.666800-1 1.880000-1 0.000000+04231 2151  100
2.000000+5 8.498600+2 0.000000+0 6.144500-1 1.880000-1 0.000000+04231 2151  101
3.000000+5 6.518200+2 0.000000+0 4.712600-1 1.880000-1 0.000000+04231 2151  102
4.000000+5 5.087700+2 0.000000+0 3.678400-1 1.880000-1 0.000000+04231 2151  103
5.000000+5 4.121400+2 0.000000+0 2.979700-1 1.880000-1 0.000000+04231 2151  104
6.000000+5 3.355200+2 0.000000+0 2.425800-1 1.880000-1 0.000000+04231 2151  105
7.000000+5 2.817800+2 0.000000+0 2.037200-1 1.880000-1 0.000000+04231 2151  106
8.000000+5 2.368900+2 0.000000+0 1.712700-1 1.880000-1 0.000000+04231 2151  107
9.000000+5 2.074200+2 7.582400-1 1.499600-1 1.880000-1 0.000000+04231 2151  108
1.000000+6 2.104200+2 9.817500+0 1.521300-1 1.880000-1 0.000000+04231 2151  109
1.500000+0 0.000000+0          5          0        114        184231 2151  110
0.000000+0 0.000000+0 2.000000+0 1.000000+0 0.000000+0 0.000000+04231 2151  111
2.000000+4 6.283100+2 0.000000+0 4.542700-1 1.880000-1 0.000000+04231 2151  112
3.000000+4 6.096400+2 0.000000+0 4.407700-1 1.880000-1 0.000000+04231 2151  113
4.000000+4 6.000400+2 0.000000+0 4.338300-1 1.880000-1 0.000000+04231 2151  114
5.000000+4 5.884200+2 0.000000+0 4.254300-1 1.880000-1 0.000000+04231 2151  115
6.000000+4 5.780200+2 0.000000+0 4.179100-1 1.880000-1 0.000000+04231 2151  116
7.000000+4 5.656900+2 0.000000+0 4.090000-1 1.880000-1 0.000000+04231 2151  117
8.000000+4 5.504800+2 0.000000+0 3.980000-1 1.880000-1 0.000000+04231 2151  118
9.000000+4 5.399000+2 0.000000+0 3.903500-1 1.880000-1 0.000000+04231 2151  119
1.000000+5 5.302100+2 0.000000+0 3.833400-1 1.880000-1 0.000000+04231 2151  120
2.000000+5 4.249300+2 0.000000+0 3.072200-1 1.880000-1 0.000000+04231 2151  121
3.000000+5 3.259100+2 0.000000+0 2.356300-1 1.880000-1 0.000000+04231 2151  122
4.000000+5 2.543900+2 0.000000+0 1.839200-1 1.880000-1 0.000000+04231 2151  123
5.000000+5 2.060700+2 0.000000+0 1.489900-1 1.880000-1 0.000000+04231 2151  124
6.000000+5 1.677600+2 0.000000+0 1.212900-1 1.880000-1 0.000000+04231 2151  125
7.000000+5 1.408900+2 0.000000+0 1.018600-1 1.880000-1 0.000000+04231 2151  126
8.000000+5 1.184400+2 0.000000+0 8.563500-2 1.880000-1 0.000000+04231 2151  127
9.000000+5 1.037100+2 7.582400-1 7.498100-2 1.880000-1 0.000000+04231 2151  128
1.000000+6 1.052100+2 9.817500+0 7.606500-2 1.880000-1 0.000000+04231 2151  129
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 9.309840+1 0.000000+0          2          0          2          04231 2151  130
 1.500000+0 0.000000+0          5          0        114         184231 2151  131
 0.000000+0 0.000000+0 1.000000+0 1.000000+0 0.000000+0 0.000000+04231 2151  132
 2.000000+4 6.283100+2 0.000000+0 4.398200-2 1.280000-1 0.000000+04231 2151  133
 3.000000+4 6.096400+2 0.000000+0 4.267500-2 1.280000-1 0.000000+04231 2151  134
 4.000000+4 6.000400+2 0.000000+0 4.200300-2 1.280000-1 0.000000+04231 2151  135
 5.000000+4 5.884200+2 0.000000+0 4.118900-2 1.280000-1 0.000000+04231 2151  136
 6.000000+4 5.780200+2 0.000000+0 4.046100-2 1.280000-1 0.000000+04231 2151  137
 7.000000+4 5.656900+2 0.000000+0 3.959800-2 1.280000-1 0.000000+04231 2151  138
 8.000000+4 5.504800+2 0.000000+0 3.853300-2 1.280000-1 0.000000+04231 2151  139
 9.000000+4 5.399000+2 0.000000+0 3.779300-2 1.280000-1 0.000000+04231 2151  140
 1.000000+5 5.302100+2 0.000000+0 3.711500-2 1.280000-1 0.000000+04231 2151  141
 2.000000+5 4.249300+2 0.000000+0 2.974500-2 1.280000-1 0.000000+04231 2151  142
 3.000000+5 3.259100+2 0.000000+0 2.281400-2 1.280000-1 0.000000+04231 2151  143
 4.000000+5 2.543900+2 0.000000+0 1.780700-2 1.280000-1 0.000000+04231 2151  144
 5.000000+5 2.060700+2 0.000000+0 1.442500-2 1.280000-1 0.000000+04231 2151  145
 6.000000+5 1.677600+2 0.000000+0 1.174300-2 1.280000-1 0.000000+04231 2151  146
 7.000000+5 1.408900+2 0.000000+0 9.862100-3 1.280000-1 0.000000+04231 2151  147
 8.000000+5 1.184400+2 0.000000+0 8.291100-3 1.280000-1 0.000000+04231 2151  148
 9.000000+5 1.037100+2 1.319800+0 7.259600-3 1.280000-1 0.000000+04231 2151  149
 1.000000+6 1.052100+2 3.337800+0 7.364600-3 1.280000-1 0.000000+04231 2151  150
 2.500000+0 0.000000+0          5          0        114         184231 2151  151
 0.000000+0 0.000000+0 1.000000+0 1.000000+0 0.000000+0 0.000000+04231 2151  152
 2.000000+4 4.188700+2 0.000000+0 2.932100-2 1.280000-1 0.000000+04231 2151  153
 3.000000+4 4.064300+2 0.000000+0 2.845000-2 1.280000-1 0.000000+04231 2151  154
 4.000000+4 4.000300+2 0.000000+0 2.800200-2 1.280000-1 0.000000+04231 2151  155
 5.000000+4 3.922800+2 0.000000+0 2.746000-2 1.280000-1 0.000000+04231 2151  156
 6.000000+4 3.853500+2 0.000000+0 2.697400-2 1.280000-1 0.000000+04231 2151  157
 7.000000+4 3.771300+2 0.000000+0 2.639900-2 1.280000-1 0.000000+04231 2151  158
 8.000000+4 3.669900+2 0.000000+0 2.568900-2 1.280000-1 0.000000+04231 2151  159
 9.000000+4 3.599400+2 0.000000+0 2.519600-2 1.280000-1 0.000000+04231 2151  160
 1.000000+5 3.534700+2 0.000000+0 2.474300-2 1.280000-1 0.000000+04231 2151  161
 2.000000+5 2.832900+2 0.000000+0 1.983000-2 1.280000-1 0.000000+04231 2151  162
 3.000000+5 2.172700+2 0.000000+0 1.520900-2 1.280000-1 0.000000+04231 2151  163
 4.000000+5 1.695900+2 0.000000+0 1.187100-2 1.280000-1 0.000000+04231 2151  164
 5.000000+5 1.373800+2 0.000000+0 9.616500-3 1.280000-1 0.000000+04231 2151  165
 6.000000+5 1.118400+2 0.000000+0 7.828800-3 1.280000-1 0.000000+04231 2151  166
 7.000000+5 9.392500+1 0.000000+0 6.574800-3 1.280000-1 0.000000+04231 2151  167
 8.000000+5 7.896300+1 0.000000+0 5.527400-3 1.280000-1 0.000000+04231 2151  168
 9.000000+5 6.913900+1 8.798500-1 4.839700-3 1.280000-1 0.000000+04231 2151  169
 1.000000+6 7.013900+1 2.225200+0 4.909700-3 1.280000-1 0.000000+04231 2151  170
                                                                   4231 2  099999
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Covariance Data

```
 0.000000+0 0.000000+0          0          0          0          04231 0  0    0
  42094.0   9.309840+1          0          0          1          0423132151    1
  42094.0   1.000000+0          0          0          1          0423132151    2
 1.000000-5 2.000000+4          1          2          0          1423132151    3
     0.0    7.000000-1          0          1          0          0423132151    4
 9.309840+1                     0          0          1          0423132151    5
                                3          0        102          4423132151    6
1542.400000       0.5   1.560000+0 1.420000+0 1.400000-1           423132151    7
108.5000000       0.5   1.881100-1 1.100000-4 1.880000-1           423132151    8
1051.300000       0.5   1.940000-1 6.000000-3 1.880000-1           423132151    9
1664.000000       1.5   1.940000-1 6.000000-3 1.880000-1           423132151   10
 1.394646+6 6.419856+2                                             423132151   11
                                                                   423132151   12
 1.586016+0                                                        423132151   13
                                                        1.254400-2423132151   14
                                                                   423132151   15
                                  4.961418+2 7.543787-4            423132151   16
                                                                   423132151   17
 8.891025-9                                                        423132151   18
                      2.262016-2                                   423132151   19
                                  4.413985+5 3.772795+0            423132151   20
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                    5.528746-5                          423132151   21
         2.262016-2                                     423132151   22
1.748991+6 9.436172+0           7.395013-5           2.262016-2423132151   23
0.000000+0 0.000000+0          0          0          0          0423132  099999
0.000000+0 0.000000+0          0          0          0          04231 0  0    0
4.209400+4 9.309840+1          0          0          0          1423133  1    1
0.000000+0 0.000000+0          0          1          0          1423133  1    2
0.000000+0 0.000000+0          1          5       1035         45423133  1    3
1.000000-5 3.000000-3 7.500000-3 1.000000-2 2.530000-2 3.000000-2423133  1    4
4.000000-2 5.000000-2 7.000000-2 1.000000-1 1.500000-1 2.000000-1423133  1    5
2.250000-1 2.500000-1 2.750000-1 3.250000-1 3.500000-1 3.750000-1423133  1    6
4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0423133  1    7
6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2423133  1    8
3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5423133  1    9
1.400000+6 1.850000+6 2.354000+6 2.479000+6 3.000000+6 4.800000+6423133  1   10
6.434000+6 8.187300+6 2.000000+7 4.075957-4 0.000000+0 0.000000+0423133  1   11
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   12
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   13
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   14
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   15
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   16
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   17
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 3.400705-4423133  1   18
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   19
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   20
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   21
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   22
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   23
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   24
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423133  1   38
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3.091000-3 3.124720-3 3.124720-3 3.025000-3 3.058000-3 3.058000-3423133  1  175
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8.352100-2 5.144200-2 9.045700-2 1.141955-1 1.693540-1 3.168400-2423133102  174
5.571400-2 7.033492-2 1.043080-1 9.796900-2 1.236788-1 1.834180-1423133102  175
1.561356-1 2.315520-1 3.433960-1 0.000000+0 0.000000+0 0.000000+0423133102  176
0.000000+0 0.000000+0          0          0          0          0423133  099999
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Resonance Parameters

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 1.000000-5 2.000000+3          1          2          0          04234 2151     3
 2.500000+0 7.000000-1          0          0          2          04234 2151     4
 9.409056+1 0.000000+0          0          0         90         154234 2151     5
-3.700000+1 2.000000+0 4.300000-1 2.580000-1 1.720000-1 0.000000+04234 2151     6
 44.6440000      3.0   3.556000-1 1.737000-1 1.819000-1            4234 2151     7
 159.365000      3.0   1.838200-1 1.382000-2 1.700000-1            4234 2151     8
 358.420000      3.0   3.720000-1 2.220000-1 1.500000-1            4234 2151     9
 661.400000      3.0   1.790000-1 9.000000-3 1.700000-1            4234 2151    10
 680.370000      3.0   1.110000+0 9.000000-1 2.100000-1            4234 2151    11
 769.900000      3.0   1.840000-1 1.400000-2 1.700000-1            4234 2151    12
 1024.80000      3.0   2.500000-1 8.000000-2 1.700000-1            4234 2151    13
 1203.70000      3.0   2.840000-1 1.440000-1 1.400000-1            4234 2151    14
 1418.70000      3.0   5.600000-1 4.200000-1 1.400000-1            4234 2151    15
 1589.60000      3.0   5.400000-1 3.600000-1 1.800000-1            4234 2151    16
 1677.60000      3.0   3.000000-1 1.200000-1 1.800000-1            4234 2151    17
 1766.20000      3.0   5.200000-1 3.300000-1 1.900000-1            4234 2151    18
 2.048100+3 3.000000+0 5.040000-1 3.540000-1 1.500000-1 0.000000+04234 2151    19
 2.130100+3 2.000000+0 1.914000+0 1.764000+0 1.500000-1 0.000000+04234 2151    20
 9.409050+1 0.000000+0          1          0        222         374234 2151    21
 110.200000      1.0   3.102500-1 2.500000-4 3.100000-1            4234 2151    22
 117.870000      2.0   2.002100-1 2.100000-4 2.000000-1            4234 2151    23
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 1122.00000      2.0   1.830000-1 3.000000-3 1.800000-1            4234 2151    42
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   44
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   45
 0.000000+0 0.000000+0 0.000000+0 3.217726-3 0.000000+0 0.000000+0423433  1   46
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   47
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   48
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   49
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   50
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   51
```

```
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   52
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   54
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   55
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   56
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   57
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   58
0.000000+0 0.000000+0 1.259185-3 0.000000+0 0.000000+0 0.000000+0423433  1   59
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   60
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   61
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   62
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   63
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   64
0.000000+0 0.000000+0 0.000000+0 1.112356-3 0.000000+0 0.000000+0423433  1   65
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   66
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   67
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   68
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   69
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   70
0.000000+0 0.000000+0 0.000000+0 9.589551-4 0.000000+0 0.000000+0423433  1   71
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   72
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   73
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   74
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   76
0.000000+0 0.000000+0 8.601902-4 0.000000+0 0.000000+0 0.000000+0423433  1   77
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   78
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   80
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   81
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8.049704-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   83
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   84
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   85
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   86
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   87
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  1   92
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```

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5.873868-4 5.898970-4 5.924072-4 5.924072-4 5.974276-4 6.175092-4423433  1  162
6.551622-4 6.829501-4 6.149990-4 2.284840-3 2.227480-3 2.227480-3423433  1  163
2.237040-3 2.246600-3 2.256160-3 2.256160-3 2.275280-3 2.351760-3423433  1  164
2.495160-3 2.600989-3 2.342200-3 2.171560-3 2.171560-3 2.180880-3423433  1  165
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2.535692-3 2.283400-3 2.171560-3 2.180880-3 2.190200-3 2.199520-3423433  1  167
2.199520-3 2.218160-3 2.292720-3 2.432520-3 2.535692-3 2.283400-3423433  1  168
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2.442960-3 2.546575-3 2.293200-3 2.209000-3 2.218400-3 2.218400-3423433  1  170
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2.227840-3 2.246720-3 2.322240-3 2.463840-3 2.568341-3 2.312800-3423433  1  172
2.227840-3 2.246720-3 2.322240-3 2.463840-3 2.568341-3 2.312800-3423433  1  173
2.265760-3 2.341920-3 2.484720-3 2.590106-3 2.332400-3 2.420640-3423433  1  174
2.568240-3 2.677169-3 2.410800-3 2.724840-3 2.840411-3 2.557800-3423433  1  175
2.960883-3 2.666286-3 2.401000-3 0.000000+0 0.000000+0 0.000000+0423433  1  176
0.000000+0 0.000000+0          0          0          0          0423433  099999
4.209500+4 9.409060+1          0          0          0          1423433  2    1
0.000000+0 0.000000+0          0          2          0          1423433  2    2
0.000000+0 0.000000+0          1          5       1035         45423433  2    3
1.000000-5 3.000000-3 7.500000-3 1.000000-2 2.530000-2 3.000000-2423433  2    4
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2.250000-1 2.500000-1 2.750000-1 3.250000-1 3.500000-1 3.750000-1423433  2    6
```

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3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5423433  2    9
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6.434000+6 8.187300+6 2.000000+7 7.845601-4 0.000000+0 0.000000+0423433  2   11
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   14
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   15
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   17
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 7.817616-4423433  2   18
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   23
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   24
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7.815379-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   26
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   27
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   28
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   34
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   35
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   36
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   37
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   43
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   44
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   45
0.000000+0 0.000000+0 0.000000+0 7.812584-4 0.000000+0 0.000000+0423433  2   46
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   47
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   48
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   51
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   54
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   55
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   56
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   57
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   58
0.000000+0 0.000000+0 6.029480-4 0.000000+0 0.000000+0 0.000000+0423433  2   59
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   62
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   63
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   67
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   68
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   72
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   73
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   74
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   81
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423433  2   87
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 4.953960-2 5.317726-2 4.008312-2 1.507984-2 1.596400-2 1.950064-2423433102  165
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 2.521744-2 2.960032-2 3.388792-2 3.781822-2 4.287600-2 4.770352-2423433102  169
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 5.082121-2 5.761800-2 6.410536-2 8.898780-2 9.552211-2 7.200116-2423433102  172
 5.671542-2 6.430050-2 7.154026-2 9.930855-2 1.066007-1 8.035181-2423433102  173
 7.290000-2 8.110800-2 1.125900-1 1.208574-1 9.109800-2 9.024016-2423433102  174
 1.252668-1 1.344650-1 1.013550-1 1.738890-1 1.866575-1 1.406958-1423433102  175
 2.003637-1 1.510270-1 1.138388-1 0.000000+0 0.000000+0 0.000000+0423433102  176
 0.000000+0 0.000000+0          0          0          0          0423433  099999
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^{96}Mo

Resonance Parameters

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 4.209600+4 9.508081+1          0          0          1          04237 2151     1
 4.209600+4 1.000000+0          0          0          2          04237 2151     2
 1.000000-5 1.900000+4          1          2          0          04237 2151     3
 0.000000+0 6.900000-1          0          0          2          04237 2151     4
 9.508081+1 0.000000+0          0          0         90        154237 2151     5
 131.171000        0.5 3.452000-1 2.598000-1 8.540000-2 0.000000+04237 2151     6
 2.366000+3 5.000000-1 3.993000+0 3.829000+0 1.640000-1 0.000000+04237 2151     7
 3.287000+3 5.000000-1 8.453000+0 8.318000+0 1.350000-1 0.000000+04237 2151     8
 3.587000+3 5.000000-1 8.099000+0 8.000000+0 9.900000-2 0.000000+04237 2151     9
 5.385000+3 5.000000-1 4.071000+0 4.000000+0 7.100000-2 0.000000+04237 2151    10
 5.800000+3 5.000000-1 3.070000-1 2.000000-1 1.070000-1 0.000000+04237 2151    11
 7.064000+3 5.000000-1 1.136000+0 1.000000+0 1.360000-1 0.000000+04237 2151    12
 7.909000+3 5.000000-1 3.096000+0 3.000000+0 9.600000-2 0.000000+04237 2151    13
 8.031000+3 5.000000-1 2.082000+0 2.000000+0 8.200000-2 0.000000+04237 2151    14
 1.000000+4 5.000000-1 2.012000+1 2.000000+1 1.200000-1 0.000000+04237 2151    15
 1.107500+4 5.000000-1 1.864000+0 1.750000+0 1.140000-1 0.000000+04237 2151    16
 1.542400+4 5.000000-1 5.124000+0 5.000000+0 1.240000-1 0.000000+04237 2151    17
 1.631700+4 5.000000-1 2.870000+0 2.700000+0 1.700000-1 0.000000+04237 2151    18
 1.796500+4 5.000000-1 1.181000+0 1.067000+0 1.140000-1 0.000000+04237 2151    19
 1.810700+4 5.000000-1 1.624000+0 1.510000+0 1.140000-1 0.000000+04237 2151    20
 9.508081+1 0.000000+0          1          0        360        604237 2151    21
 113.290000        0.5 1.364200-1 4.200000-4 1.360000-1 0.000000+04237 2151    22
 419.060000        0.5 1.419000-1 5.900000-3 1.360000-1 0.000000+04237 2151    23
 968.400000        0.5 1.384000-1 2.400000-3 1.360000-1 0.000000+04237 2151    24
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 1498.40000        0.5 1.460000-1 1.000000-2 1.360000-1 0.000000+04237 2151    26
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 3.764000+3 1.500000+0 2.800000-1 2.000000-1 8.000000-2 0.000000+04237 2151    31
 4.326000+3 5.000000-1 4.280000-1 3.340000-1 9.400000-2 0.000000+04237 2151    32
 4.420000+3 5.000000-1 3.880000-1 2.520000-1 1.360000-1 0.000000+04237 2151    33
 4.567000+3 5.000000-1 1.887000-1 5.270000-2 1.360000-1 0.000000+04237 2151    34
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 5.413000+3 5.000000-1 2.530000-1 1.170000-1 1.360000-1 0.000000+04237 2151    36
 5.619000+3 1.500000+0 6.250000-1 5.000000-1 1.250000-1 0.000000+04237 2151    37
 6.046000+3 1.500000+0 1.091000+0 1.000000+0 9.100000-2 0.000000+04237 2151    38
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5.000000-1 0.000000+0          5          0        120        194237 2151  107
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3.000000+4 7.462100+2 0.000000+0 3.731100-1 1.250000-1 0.000000+04237 2151  111
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7.000000+4 6.995800+2 0.000000+0 3.497900-1 1.250000-1 0.000000+04237 2151  115
8.000000+4 6.777900+2 0.000000+0 3.389000-1 1.250000-1 0.000000+04237 2151  116
9.000000+4 6.636800+2 0.000000+0 3.318400-1 1.250000-1 0.000000+04237 2151  117
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6.000000+5 2.069200+2 0.000000+0 1.034600-1 1.250000-1 0.000000+04237 2151  123
7.000000+5 1.729400+2 0.000000+0 8.647200-2 1.250000-1 0.000000+04237 2151  124
8.000000+5 1.564600+2 2.342300-1 7.823000-2 1.250000-1 0.000000+04237 2151  125
9.000000+5 1.699100+2 5.177900+0 8.495300-2 1.250000-1 0.000000+04237 2151  126
1.000000+6 1.524400+2 1.033500+1 7.622200-2 1.250000-1 0.000000+04237 2151  127
1.500000+0 0.000000+0          5          0        120         194237 2151  128
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8.000000+4 3.389000+2 0.000000+0 1.694500-1 1.250000-1 0.000000+04237 2151  137
9.000000+4 3.318400+2 0.000000+0 1.659200-1 1.250000-1 0.000000+04237 2151  138
1.000000+5 3.263500+2 0.000000+0 1.631700-1 1.250000-1 0.000000+04237 2151  139
2.000000+5 2.516900+2 0.000000+0 1.258400-1 1.250000-1 0.000000+04237 2151  140
3.000000+5 1.956900+2 0.000000+0 9.784400-2 1.250000-1 0.000000+04237 2151  141
4.000000+5 1.555600+2 0.000000+0 7.777800-2 1.250000-1 0.000000+04237 2151  142
5.000000+5 1.261200+2 0.000000+0 6.305800-2 1.250000-1 0.000000+04237 2151  143
6.000000+5 1.034600+2 0.000000+0 5.173000-2 1.250000-1 0.000000+04237 2151  144
7.000000+5 8.647200+1 0.000000+0 4.323600-2 1.250000-1 0.000000+04237 2151  145
8.000000+5 7.823000+1 2.342300-1 3.911500-2 1.250000-1 0.000000+04237 2151  146
9.000000+5 8.495300+1 5.177900+0 4.247700-2 1.250000-1 0.000000+04237 2151  147
1.000000+6 7.622200+1 1.033500+1 3.811100-2 1.250000-1 0.000000+04237 2151  148
9.508081+1 0.000000+0          2          0          2          04237 2151  149
1.500000+0 0.000000+0          5          0        120         194237 2151  150
0.000000+0 0.000000+0 1.000000+0 1.000000+0 0.000000+0 0.000000+04237 2151  151
1.900000+4 3.667900+2 0.000000+0 2.310800-2 9.600000-2 0.000000+04237 2151  152
2.000000+4 3.767500+2 0.000000+0 2.373500-2 9.600000-2 0.000000+04237 2151  153
3.000000+4 3.731100+2 0.000000+0 2.350600-2 9.600000-2 0.000000+04237 2151  154
4.000000+4 3.686400+2 0.000000+0 2.322400-2 9.600000-2 0.000000+04237 2151  155
5.000000+4 3.632200+2 0.000000+0 2.288300-2 9.600000-2 0.000000+04237 2151  156
6.000000+4 3.575400+2 0.000000+0 2.252500-2 9.600000-2 0.000000+04237 2151  157
7.000000+4 3.497900+2 0.000000+0 2.203700-2 9.600000-2 0.000000+04237 2151  158
8.000000+4 3.389000+2 0.000000+0 2.135000-2 9.600000-2 0.000000+04237 2151  159
9.000000+4 3.318400+2 0.000000+0 2.090600-2 9.600000-2 0.000000+04237 2151  160
1.000000+5 3.263500+2 0.000000+0 2.056000-2 9.600000-2 0.000000+04237 2151  161
2.000000+5 2.516900+2 0.000000+0 1.585600-2 9.600000-2 0.000000+04237 2151  162
3.000000+5 1.956900+2 0.000000+0 1.232800-2 9.600000-2 0.000000+04237 2151  163
4.000000+5 1.555600+2 0.000000+0 9.800000-3 9.600000-2 0.000000+04237 2151  164
5.000000+5 1.261200+2 0.000000+0 7.945300-3 9.600000-2 0.000000+04237 2151  165
6.000000+5 1.034600+2 0.000000+0 6.518000-3 9.600000-2 0.000000+04237 2151  166
7.000000+5 8.647200+1 0.000000+0 5.447700-3 9.600000-2 0.000000+04237 2151  167
8.000000+5 7.823000+1 5.960500-1 4.928500-3 9.600000-2 0.000000+04237 2151  168
9.000000+5 8.495300+1 1.890400+0 5.352100-3 9.600000-2 0.000000+04237 2151  169
1.000000+6 7.622200+1 2.377100+0 4.802000-3 9.600000-2 0.000000+04237 2151  170
2.500000+0 0.000000+0          5          0        120         194237 2151  171
0.000000+0 0.000000+0 1.000000+0 1.000000+0 0.000000+0 0.000000+04237 2151  172
1.900000+4 2.445300+2 0.000000+0 1.540500-2 9.600000-2 0.000000+04237 2151  173
2.000000+4 2.511700+2 0.000000+0 1.582300-2 9.600000-2 0.000000+04237 2151  174
3.000000+4 2.487400+2 0.000000+0 1.567100-2 9.600000-2 0.000000+04237 2151  175
4.000000+4 2.457600+2 0.000000+0 1.548300-2 9.600000-2 0.000000+04237 2151  176
5.000000+4 2.421500+2 0.000000+0 1.525500-2 9.600000-2 0.000000+04237 2151  177
```

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 6.000000+4 2.383600+2 0.000000+0 1.501700-2 9.600000-2 0.000000+04237 2151  178
 7.000000+4 2.331900+2 0.000000+0 1.469100-2 9.600000-2 0.000000+04237 2151  179
 8.000000+4 2.259300+2 0.000000+0 1.423400-2 9.600000-2 0.000000+04237 2151  180
 9.000000+4 2.212300+2 0.000000+0 1.393700-2 9.600000-2 0.000000+04237 2151  181
 1.000000+5 2.175700+2 0.000000+0 1.370700-2 9.600000-2 0.000000+04237 2151  182
 2.000000+5 1.677900+2 0.000000+0 1.057100-2 9.600000-2 0.000000+04237 2151  183
 3.000000+5 1.304600+2 0.000000+0 8.218900-3 9.600000-2 0.000000+04237 2151  184
 4.000000+5 1.037000+2 0.000000+0 6.533300-3 9.600000-2 0.000000+04237 2151  185
 5.000000+5 8.407800+1 0.000000+0 5.296900-3 9.600000-2 0.000000+04237 2151  186
 6.000000+5 6.897300+1 0.000000+0 4.345300-3 9.600000-2 0.000000+04237 2151  187
 7.000000+5 5.764800+1 0.000000+0 3.631800-3 9.600000-2 0.000000+04237 2151  188
 8.000000+5 5.215300+1 3.973700-1 3.285600-3 9.600000-2 0.000000+04237 2151  189
 9.000000+5 5.663500+1 1.260300+0 3.568000-3 9.600000-2 0.000000+04237 2151  190
 1.000000+6 5.081500+1 1.584700+0 3.201300-3 9.600000-2 0.000000+04237 2151  191
                                                                  4237 2  099999
```

Covariance Data

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0.000000+0 0.000000+0          0          0          0          04237 0  0    0
  42096.0   9.508080+1          0          0          1          0423732151    1
  42096.0   1.000000+0          0          0          1          0423732151    2
 1.000000-5 1.900000+4          1          2          0          1423732151    3
     0.0   7.000000-1          0          1          0          0423732151    4
 9.508080+1                     0          0          1          0423732151    5
                                3          0         63          3423732151    6
131.1710000      0.5    3.452000-1 2.598000-1 8.540000-2          423732151    7
113.2900000      0.5    1.364200-1 4.200000-4 1.360000-1          423732151    8
419.0600000      0.5    1.419000-1 5.900000-3 1.360000-1          423732151    9
 8.449829-5-1.504718-5 6.865532-7 1.137985-8 4.78522-11 4.031212-8423732151   10
-1.354975-7-1.231459-9-3.921703-8 2.682354-4-1.758360-5-1.017361-7423732151   11
-3.25748-10-1.023846-7 5.286876-7 1.559265-8 3.271907-6 5.700454-6423732151   12
-8.02752-10 1.48355-10-1.515247-8 2.234351-8 2.525425-9-2.214231-9423732151   13
 6.155148-4 3.069553-8 2.367844-5-3.752552-8-3.59442-13 8.832315-8423732151   14
 1.198195-9 1.345105-6 5.94097-10 4.02802-11 7.050314-9 3.820072-3423732151   15
 8.585841-7 4.366537-8 9.361430-6 2.027010-3-2.004630-6 6.990560-4423732151   16
 9.148947-8 3.010841-6 7.826025-3                                 423732151   17
      0.0        0.0            0          0          0          0423732  0   18
      0.0        0.0            0          0          0          04237 0  0   19
      0.0        0.0            0          0          0          0423732  099999
      0.0        0.0            0          0          0          04237 0  0    0
 4.209600+4 9.508080+1          0          0          0          1423733  1    1
 0.000000+0 0.000000+0          0          1          0          1423733  1    2
 0.000000+0 0.000000+0          1          5       1035         45423733  1    3
 1.000000-5 3.000000-3 7.500000-3 1.000000-2 2.530000-2 3.000000-2423733  1    4
 4.000000-2 5.000000-2 7.000000-2 1.000000-1 1.500000-1 2.000000-1423733  1    5
 2.250000-1 2.500000-1 2.750000-1 3.250000-1 3.500000-1 3.750000-1423733  1    6
 4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0423733  1    7
 6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2423733  1    8
 3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5423733  1    9
 1.400000+6 1.850000+6 2.354000+6 2.479000+6 3.000000+6 4.800000+6423733  1   10
 6.434000+6 8.187300+6 2.000000+7 2.246701-4 0.000000+0 0.000000+0423733  1   11
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   12
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   13
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   14
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   15
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 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   23
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   24
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   25
 3.492040-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   26
 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   27
```

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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   28
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   32
3.510002-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   33
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 3.474123-4423733  1   39
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1   43
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4.399087-4 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0423733  1  159
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3.764211-3 3.439542-3 3.254421-3 5.155240-3 4.638280-3 4.595200-3423733  2  163
5.155240-3 6.045560-3 7.122560-3 7.882204-3 9.219120-3 1.026740-2423733  2  164
1.049716-2 9.591762-3 9.075520-3 4.173160-3 4.134400-3 4.638280-3423733  2  165
5.439320-3 6.408320-3 7.091788-3 8.294640-3 9.237800-3 9.444520-3423733  2  166
8.629914-3 8.165440-3 4.096000-3 4.595200-3 5.388800-3 6.348800-3423733  2  167
7.025920-3 8.217600-3 9.152000-3 9.356800-3 8.549760-3 8.089600-3423733  2  168
5.155240-3 6.045560-3 7.122560-3 7.882204-3 9.219120-3 1.026740-2423733  2  169
1.049716-2 9.591762-3 9.075520-3 7.089640-3 8.352640-3 9.243476-3423733  2  170
1.081128-2 1.204060-2 1.231004-2 1.124828-2 1.064288-2 9.840640-3423733  2  171
1.089018-2 1.273728-2 1.418560-2 1.450304-2 1.325213-2 1.253888-2423733  2  172
1.205165-2 1.409575-2 1.569854-2 1.604984-2 1.466551-2 1.387619-2423733  2  173
1.648656-2 1.836120-2 1.877208-2 1.715296-2 1.622976-2 2.044900-2423733  2  174
2.090660-2 1.910337-2 1.807520-2 2.137444-2 1.953086-2 1.847968-2423733  2  175
1.784629-2 1.688578-2 1.597696-2 0.000000+0 0.000000+0 0.000000+0423733  2  176
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0.000000+0 0.000000+0          1          5       1035         45423733102    3
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0.000000+0 0.000000+0 0.000000+0 1.151973-2 0.000000+0 0.000000+0423733102  130
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0.000000+0 0.000000+0 3.097600-2 2.400640-2 2.266880-2 2.488640-2423733102  161
3.463680-2 3.850880-2 4.642880-2 5.094672-2 6.019200-2 7.001280-2423733102  162
9.074560-2 1.056563-1 1.056000-1 1.860496-2 1.756832-2 1.928696-2423733102  163
2.684352-2 2.984432-2 3.598232-2 3.948371-2 4.664880-2 5.425992-2423733102  164
7.032784-2 8.188365-2 8.184000-2 1.658944-2 1.821232-2 2.534784-2423733102  165
2.818144-2 3.397744-2 3.728374-2 4.404960-2 5.123664-2 6.640928-2423733102  166
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4.093106-2 4.835880-2 5.624892-2 7.290584-2 8.488525-2 8.484000-2423733102  168
3.873024-2 4.305984-2 5.191584-2 5.696770-2 6.730560-2 7.828704-2423733102  169
1.014701-1 1.181430-1 1.180800-1 4.787344-2 5.771944-2 6.333604-2423733102  170
7.482960-2 8.703864-2 1.128133-1 1.313500-1 1.312800-1 6.959044-2423733102  171
7.636219-2 9.021960-2 1.049396-1 1.360153-1 1.583644-1 1.582800-1423733102  172
8.379288-2 9.899874-2 1.151512-1 1.492507-1 1.737746-1 1.736820-1423733102  173
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2.051057-1 2.388073-1 2.386800-1 2.658434-1 3.095250-1 3.093600-1423733102  175
3.603841-1 3.601920-1 3.600000-1 0.000000+0 0.000000+0 0.000000+0423733102  176
0.000000+0 0.000000+0          0          0          0          0423733  099999
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^{97}Mo

Resonance Parameters

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 4.209700+4 1.000000+0          0          0          2          04240 2151     2
 1.000000-5 1.800000+3          1          2          0          04240 2151     3
 2.500000+0 6.900000-1          0          0          2          04240 2151     4
 9.607355+1 0.000000+0          0          0        162        274240 2151     5
-6.850000+1 2.000000+0 4.710000-1 3.000000-1 1.710000-1 0.000000+04240 2151     6
 70.8390000        2.0 1.588600-1 1.886000-2 1.400000-1 0.000000+04240 2151     7
 267.900000        3.0 1.347000-1 1.470000-2 1.200000-1 0.000000+04240 2151     8
 285.855000        2.0 2.400000-1 1.050000-1 1.350000-1 0.000000+04240 2151     9
 311.770000        3.0 1.286000-1 8.600000-3 1.200000-1 0.000000+04240 2151    10
 396.990000        3.0 2.100000-1 7.000000-2 1.400000-1 0.000000+04240 2151    11
 505.090000        2.0 2.350000-1 7.500000-2 1.600000-1 0.000000+04240 2151    12
 557.830000        3.0 5.920000-1 4.730000-1 1.190000-1 0.000000+04240 2151    13
 675.700000        3.0 5.320000-1 3.120000-1 2.200000-1 0.000000+04240 2151    14
 786.030000        3.0 4.200000-1 3.000000-1 1.200000-1 0.000000+04240 2151    15
 862.500000        2.0 1.780000-1 3.800000-2 1.400000-1 0.000000+04240 2151    16
 1008.50000        2.0 2.000000-1 6.000000-2 1.400000-1 0.000000+04240 2151    17
 1107.87000        2.0 5.900000-1 4.700000-1 1.200000-1 0.000000+04240 2151    18
 1133.70000        2.0 1.620000-1 2.200000-2 1.400000-1 0.000000+04240 2151    19
 1176.70000        2.0 1.920000-1 5.200000-2 1.400000-1 0.000000+04240 2151    20
 1249.60000        3.0 1.370000+0 1.240000+0 1.300000-1 0.000000+04240 2151    21
 1271.60000        3.0 1.400000-1 2.000000-2 1.200000-1 0.000000+04240 2151    22
 1290.90000        3.0 1.410000-1 2.100000-2 1.200000-1 0.000000+04240 2151    23
 1319.00000        2.0 1.590000-1 1.900000-2 1.400000-1 0.000000+04240 2151    24
 1365.00000        3.0 1.680000-1 4.800000-2 1.200000-1 0.000000+04240 2151    25
 1423.40000        3.0 1.700000-1 5.000000-2 1.200000-1 0.000000+04240 2151    26
 1534.80000        2.0 1.720000+0 1.570000+0 1.500000-1 0.000000+04240 2151    27
 1597.30000        2.0 2.100000-1 7.000000-2 1.400000-1 0.000000+04240 2151    28
 1695.40000        3.0 2.700000-1 1.100000-1 1.600000-1 0.000000+04240 2151    29
 1713.00000        2.0 5.300000-1 3.900000-1 1.400000-1 0.000000+04240 2151    30
 1934.00000        2.0 1.900000-1 5.000000-2 1.400000-1 0.000000+04240 2151    31
 1942.80000        3.0 1.600000-1 4.000000-2 1.200000-1 0.000000+04240 2151    32
 9.607355+1 0.000000+0          1          0        210        354240 2151    33
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 127.010000        1.0 2.105200-1 5.200000-4 2.100000-1 0.000000+04240 2151    36
 136.220000        4.0 2.104500-1 4.500000-4 2.100000-1 0.000000+04240 2151    37
 209.500000        4.0 2.105000-1 5.000000-4 2.100000-1 0.000000+04240 2151    38
 227.420000        3.0 2.117000-1 1.700000-3 2.100000-1 0.000000+04240 2151    39
 233.300000        3.0 2.106000-1 6.000000-4 2.100000-1 0.000000+04240 2151    40
 248.000000        4.0 2.111000-1 1.100000-3 2.100000-1 0.000000+04240 2151    41
 320.900000        4.0 2.111000-1 1.100000-3 2.100000-1 0.000000+04240 2151    42
 352.540000        3.0 2.186000-1 8.600000-3 2.100000-1 0.000000+04240 2151    43
 380.790000        3.0 2.159000-1 5.900000-3 2.100000-1 0.000000+04240 2151    44
 457.500000        2.0 2.122000-1 2.200000-3 2.100000-1 0.000000+04240 2151    45
 528.900000        3.0 2.112000-1 1.200000-3 2.100000-1 0.000000+04240 2151    46
 533.700000        3.0 2.135000-1 3.500000-3 2.100000-1 0.000000+04240 2151    47
 548.300000        3.0 2.143000-1 4.300000-3 2.100000-1 0.000000+04240 2151    48
 564.100000        3.0 2.122000-1 2.200000-3 2.100000-1 0.000000+04240 2151    49
 568.000000        3.0 2.150000-1 5.000000-3 2.100000-1 0.000000+04240 2151    50
 571.200000        2.0 2.170000-1 7.000000-3 2.100000-1 0.000000+04240 2151    51
 579.500000        4.0 2.111000-1 1.100000-3 2.100000-1 0.000000+04240 2151    52
 653.100000        4.0 2.120000-1 2.000000-3 2.100000-1 0.000000+04240 2151    53
 694.400000        2.0 2.210000-1 1.100000-2 2.100000-1 0.000000+04240 2151    54
 699.400000        4.0 2.150000-1 5.000000-3 2.100000-1 0.000000+04240 2151    55
 809.600000        2.0 2.140000-1 4.000000-3 2.100000-1 0.000000+04240 2151    56
 906.300000        4.0 2.170000-1 7.000000-3 2.100000-1 0.000000+04240 2151    57
 976.000000        2.0 2.230000-1 1.300000-2 2.100000-1 0.000000+04240 2151    58
 1333.40000        4.0 2.360000-1 2.600000-2 2.100000-1 0.000000+04240 2151    59
 1375.60000        3.0 2.230000-1 1.300000-2 2.100000-1 0.000000+04240 2151    60
 1398.60000        3.0 2.210000-1 1.100000-2 2.100000-1 0.000000+04240 2151    61
 1493.00000        3.0 2.200000-1 1.000000-2 2.100000-1 0.000000+04240 2151    62
 1553.00000        1.0 2.220000-1 1.200000-2 2.100000-1 0.000000+04240 2151    63
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1834.00000       3.0   2.220000-1 1.200000-2 2.100000-1 0.000000+04240 2151   66
1868.00000       1.0   2.500000-1 4.000000-2 2.100000-1 0.000000+04240 2151   67
1868.00000       4.0   2.220000-1 1.200000-2 2.100000-1 0.000000+04240 2151   68
1.800000+3 3.000000+5          2          2          0          04240 2151   69
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9.607355+1 0.000000+0          0          0          2          04240 2151   71
2.000000+0 0.000000+0          5          0        132         214240 2151   72
0.000000+0 0.000000+0 0.000000+0 1.000000+0 0.000000+0 0.000000+04240 2151   73
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8.000000+3 1.860000+2 0.000000+0 1.460100-1 1.300000-1 0.000000+04240 2151  128
9.000000+3 1.860000+2 0.000000+0 1.460100-1 1.300000-1 0.000000+04240 2151  129
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3.000000+5 7.971400+1 0.000000+0 6.257600-2 1.300000-1 0.000000+04240 2151  187
4.000000+0 0.000000+0          5          0        132         214240 2151  188
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Covariance Data

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     0.0    7.000000-1          0          1          0          0424032151    4
 9.607350+1                     0          0          1          0424032151    5
                                3          0       3237         26424032151    6
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285.8550000      2.0    2.400000-1 1.050000-1 1.350000-1           424032151    9
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396.9900000      3.0    2.100000-1 7.000000-2 1.400000-1           424032151   11
505.0900000      2.0    2.350000-1 7.500000-2 1.600000-1           424032151   12
557.8300000      3.0    5.920000-1 4.730000-1 1.190000-1           424032151   13
79.50000000      1.0    1.201600-1 1.600000-4 1.200000-1           424032151   14
109.2000000      1.0    2.103700-1 3.700000-4 2.100000-1           424032151   15
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   45
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   47
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   48
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   55
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   56
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424033  1   57
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2.265760-3 2.227680-3 2.142000-3 2.142190-3 2.170560-3 2.190240-3424033  1  174
2.106000-3 2.106187-3 2.134080-3 2.025000-3 2.025180-3 2.052000-3424033  1  175
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 8.274828-4424033  2   39
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0.000000+0 0.000000+0 0.000000+0 8.274828-4 0.000000+0 0.000000+0424033  2   46
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Resonance Parameters

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 0.000000+0 6.600000-1          0          0          2          04243 2151     4
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-7.000000+2 5.000000-1 3.858400+0 3.800000+0 5.840000-2 0.000000+04243 2151     6
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 1526.40000        0.5 1.460000+0 1.390000+0 7.000000-2 0.000000+04243 2151     8
 2.553000+3 5.000000-1 1.700000-1 1.000000-1 7.000000-2 0.000000+04243 2151     9
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 4.486000+3 5.000000-1 5.120000-1 4.280000-1 8.400000-2 0.000000+04243 2151    11
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2.833000+4 5.000000-1 4.800000-1 3.600000-1 1.200000-1 0.000000+04243 2151  132
2.892000+4 1.500000+0 2.770000-1 1.570000-1 1.200000-1 0.000000+04243 2151  133
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3.017000+4 1.500000+0 4.430000-1 3.230000-1 1.200000-1 0.000000+04243 2151  138
3.046000+4 5.000000-1 2.570000-1 1.370000-1 1.200000-1 0.000000+04243 2151  139
3.068000+4 1.500000+0 4.329000+0 4.115000+0 2.140000-1 0.000000+04243 2151  140
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3.381000+4 5.000000-1 3.240000+0 3.120000+0 1.200000-1 0.000000+04243 2151  147
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5.000000-1 0.000000+0          5          0        108        174243 2151  188
0.000000+0 0.000000+0 2.000000+0 1.000000+0 0.000000+0 0.000000+04243 2151  189
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      Covariance Data

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  42098.0   1.000000+0          0          0          1          0424332151    2
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     0.0    7.000000-1          0          1          0          0424332151    4
 9.706430+1                     0          0          1          0424332151    5
                                3          0        102          4424332151    6
467.4540000      0.5    8.705000-1 7.820000-1 8.850000-2          424332151    7
12.07000000      1.5    1.200309-1 3.090000-5 1.200000-1          424332151    8
401.4400000      1.5    1.213800-1 1.380000-3 1.200000-1          424332151    9
429.2030000      0.5    1.805000-1 6.750000-2 1.130000-1          424332151   10
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      0.0        0.0            0          0          0          04243 0  018929
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0.000000+0 0.000000+0 0.000000+0 4.322657-4 0.000000+0 0.000000+0424333  1   46
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1.440000-3 1.472032-3 1.504000-3 2.025000-3 2.025000-3 2.025000-3424333  1  163
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2.116000-3 2.116000-3 2.070000-3 2.116046-3 2.162000-3 2.116000-3424333  1  174
2.070000-3 2.116046-3 2.162000-3 2.025000-3 2.070045-3 2.115000-3424333  1  175
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0.000000+0 0.000000+0          0          0          0          0424333  099999
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0.000000+0 0.000000+0          0        102          0          1424333102    2
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1.000000-5 3.000000-3 7.500000-3 1.000000-2 2.530000-2 3.000000-2424333102    4
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4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0424333102    7
6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2424333102    8
3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5424333102    9
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1.404000-2 1.417005-2 2.007000-2 5.041000-3 5.325000-3 5.041000-3424333102  163
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Resonance Parameters

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 1.000000-5 2.600000+4          1          2          0          04249 2151    3
 0.000000+0 6.900000-1          0          0          2          04249 2151    4
 9.904922+1 0.000000+0          0          0        198        334249 2151    5
-6.000000+2 5.000000-1 3.764400+0 3.700000+0 6.440000-2 0.000000+04249 2151    6
 363.924000       0.5  6.600000-1 6.040000-1 5.600000-2 0.000000+04249 2151    7
 1404.30000       0.5  1.630000-1 1.070000-1 5.600000-2 0.000000+04249 2151    8
 1937.30000       0.5  9.800000-1 9.200000-1 6.000000-2 0.000000+04249 2151    9
 2.636000+3 5.000000-1 4.750000-1 4.100000-1 6.500000-2 0.000000+04249 2151   10
 3.015000+3 5.000000-1 2.000000+0 1.950000+0 5.000000-2 0.000000+04249 2151   11
 4.521000+3 5.000000-1 9.510000-1 8.700000-1 8.100000-2 0.000000+04249 2151   12
 4.745000+3 5.000000-1 2.630000-1 1.950000-1 6.800000-2 0.000000+04249 2151   13
 5.168000+3 5.000000-1 5.550000+0 5.480000+0 7.000000-2 0.000000+04249 2151   14
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 7.273000+3 5.000000-1 4.750000+0 4.680000+0 7.000000-2 0.000000+04249 2151   16
 7.673000+3 5.000000-1 6.051000+0 6.000000+0 5.100000-2 0.000000+04249 2151   17
 8.440000+3 5.000000-1 5.290000-1 4.700000-1 5.900000-2 0.000000+04249 2151   18
 8.800000+3 5.000000-1 1.092000+0 1.030000+0 6.200000-2 0.000000+04249 2151   19
 9.658000+3 5.000000-1 2.967000+0 2.900000+0 6.700000-2 0.000000+04249 2151   20
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0.000000+0 6.098900-1          1          0          3          04249 2151  132
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5.000000-1 0.000000+0          5          0        114        184249 2151  134
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4.000000+4 6.170000+2 0.000000+0 3.948800-2 6.400000-2 0.000000+04249 2151  138
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4.000000+5 2.470800+2 0.000000+0 1.581300-2 6.400000-2 0.000000+04249 2151  147
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9.904922+1 0.000000+0          1          0          2          04249 2151  154
5.000000-1 0.000000+0          5          0        114        184249 2151  155
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      Covariance Data
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   85
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   86
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   87
0.000000+0 0.000000+0 0.000000+0 8.015621-3 0.000000+0 0.000000+0424933  1   88
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   89
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   90
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   91
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   92
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 8.031924-3424933  1   93
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   94
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   95
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   96
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   97
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1   98
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1  101
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  1  129
0.000000+0 0.000000+0 0.000000+0 8.083089-3 0.000000+0 0.000000+0424933  1  130
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4.724568-3 4.793211-3 4.947102-3 3.047040-3 3.069120-3 3.047040-3424933  1  163
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3.047040-3 3.091310-3 3.190560-3 3.091360-3 3.069120-3 3.080240-3424933  1  165
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4.000000-1 6.250000-1 1.000000+0 1.770000+0 3.000000+0 4.750000+0424933  2    7
6.000000+0 8.100000+0 1.000000+1 3.000000+1 1.000000+2 5.500000+2424933  2    8
3.000000+3 1.700000+4 2.500000+4 1.000000+5 4.000000+5 9.000000+5424933  2    9
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6.434000+6 8.187300+6 2.000000+7 7.116090-4 0.000000+0 0.000000+0424933  2   11
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 6.486700-4424933  2   18
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  2   85
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  2   86
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  2   87
0.000000+0 0.000000+0 0.000000+0 8.171256-3 0.000000+0 0.000000+0424933  2   88
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0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  2   90
0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0 0.000000+0424933  2   91
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